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Technologies and Costs for the Removal of Synthetic Organic Chemicals from Potable Water Supplies

(U.S.) Environmental Protection Agency, Washington, DC

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16. ABSTRACT

This document covers various types of treatment (removal) of several synthetic organic compounds and their cost for this treatment. The best available technologies are discussed in relation to their removal of organic contaminants for drinking water.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
cost, best available technology, treatment		

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TECHNOLOGIES AND COSTS FOR THE REMOVAL OF SYNTHETIC ORGANIC CHEMICALS FROM POTABLE WATER SUPPLIES

SCIENCE AND TECHNOLOGY BRANCH
CRITERIA AND STANDARDS DIVISION
OFFICE OF DRINKING WATER
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C.

NOTICE

This document is the final version of the Technology and Cost document for Phase II SOCs. It is identical to the March 1989 draft of the document with the following exceptions:

1. The following figures and tables detailing GAC costs have been replaced with updated figures and tables based on work by Adams and Clark (1989). The tables were developed by Malcolm Pirnie for EPA and included in a letter dated March 28, 1990, to Dave Huber.

March 1989 Draft	Replaced By
Figure 7-1	Figure 7-1
Figure 7-2	Figure 7-2
Figure 7-3	not replaced (a)
Table 7-6	Table 7-6
Appendix F (28 tables)	Appendix F (28 tables)

(a) Figure 7-3 was not replaced because the data is now included in Figure 7-2.

Costs developed were based on an EBCT = 10 minutes at design flow. The 10-minute EBCT at design flow resulted in an EBCT above 15 minutes in all 12 size categories at average flow, and at least 12 minutes for all categories at the 90 percentile flow rate. A pen-and-ink correction has been made to this assumption on p. 7-3.

2. Table 7-25 has been added. This table details the additional costs for vapor phase carbon emission controls for packed tower aeration facilities, if such controls are required.

3. Section 8 (References) now includes additional references on p. 8-10.

4. Appendix H has been added. It contains the March 28, 1990, letter from Malcolm Pirnie to Dave Huber transmitting the revised GAC cost data referred to in Item 1. above.

5. Appendix I has been added. It contains the February 28, 1990 memo from Malcolm Pirnie to Dave Huber transmitting data concerning additional costs for vapor phase carbon emission controls for packed tower aeration facilities referred to in Item 2. above.

U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C.

TECHNOLOGIES AND COSTS FOR THE REMOVAL OF SYNTHETIC ORGANIC CHEMICALS FROM POTABLE WATER SUPPLIES

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1. INTRODUCTION

Purpose and Scope

The 1986 Amendments to the Safe Drinking Water Act (SDWA) require the United States Environmental Protection Agency (EPA) to set maximum contaminant levels (MCLs) for several contaminants found in drinking water. The MCLs are to be established based upon:

1. Health goals
2. Effectiveness of treatment technologies in removing the contaminants
3. Level of treatment that is affordable for the water supply systems

In order to establish the MCLs, the SDWA Amendments emphasize a shift from "generally available" treatment technologies to "best available treatment" (BAT) technologies. All public water systems will be required to come as close as possible to meeting the MCLs by using the BAT technology. EPA is currently establishing MCLs for a number of synthetic organic chemicals (SOCs) which might occur in contaminated water supplies. A list of SOCs to be regulated is shown in Table 1-1.

The purpose of this document is to assist EPA in defining BAT technology for removing SOCs from water supplies. Additionally, the document can also assist water utilities in selecting appropriate treatment methods to meet the regulations. The treatment and compliance methods available to a community searching for the most economical and effective means to comply with the proposed SOC MCLs include modification of existing treatment systems, installation of new systems, and the use of nontreatment alternatives, such as regionalization or alternate raw water sources. The major factors that must be considered in selecting a compliance method include:

1. Quality and type of water source
2. Degree of SOC contamination
3. Specific compound(s) present in water source
4. Economies of scale and the economic stability of the community being served
5. Treatment and waste disposal requirements

TABLE 1-1

PHASE II SOCs TO BE REGULATED

Acrylamide
Alachlor
Aldicarb
Aldicarb Sulfone
Aldicarb Sulfoxide
Atrazine
Carbofuran
Chlordane
Dibromochloropropane (DBCP)
o-Dichlorobenzene
cis-1,2-Dichloroethylene
trans-1,2-Dichloroethylene
1,2-Dichloropropane
2,4-D
Epichlorohydrin
Ethylbenzene
Ethylene dibromide (EDB)
Heptachlor
Heptachlor epoxide
Lindane
Methoxychlor
Monochlorobenzene
Polychlorinated biphenyls (PCBs)
Pentachlorophenol
Styrene
Tetrachloroethylene
Toluene
Toxaphene
2,4,5-TP (Silvex)
Xylenes (Total)
  - O-xylene
  - m-xylene
  - p-xylene

Organization of Document

This document has been organized into seven sections which are outlined below:

1. Introduction: Discusses purpose and scope of the document, lists the SOCS under consideration and presents the organization of the document.

2. Description of SOCs: Presents the chemical structures, names, uses and chemical/physical properties for each SOC.

3. Description of Available Technologies: Summarizes the available technologies for SOC removal, provides process descriptions of each available technology and ranks the technologies according to their applicability for SOC treatment (most applicable, other applicable, and additional technologies).

4. Most Applicable Technologies: Summarizes the available treatability information to date for the most applicable technologies and develops design criteria for each SOC that can be removed by these technologies.

5. Other Applicable Technologies: Summarizes the available treatability information to date for the other applicable technologies and develops design criteria for each SOC that can be removed by these technologies.

6. Additional Technologies: Summarizes the available treatability information to date for any additional technologies that show some potential for removing SOCs.

7. Costs: Develops cost information for the applicable technologies. Also presents cost for the removal of Tetrachloroethylene by GAC and PTA.

8. References

8

2. DESCRIPTION OF SOCs

This section provides the names, uses, chemical/physical properties and chemical structures of each of the 29 SOCs. The potential routes of entry of these SOCs into the environment are also presented at the end of this section.

ACRYLAMIDE

Chemical/Physical Properties

Molecular Weight:	71.08
Melting Point:	84-5 C
Vapor Pressure:	2 mm Hg at 87 C
	10 mm Hg at 117 C
Solubility in Water:	2.15×10^6 mg/L (30 C)

Uses

Acrylamide is principally used in the synthesis of water-soluble polymers which are used as flocculants in potable water treatment and wastewater treatment plants, papermaking aids, thickeners, and additives for enhanced oil recovery. It is also used frequently as a component of photopolymerizable systems. Acrylamide monomer is marketed as a chemical grouping agent and soil stabilizer utilized in dams, foundations, and tunnels. The structural formula of acrylamide is shown on Figure 2-1.

ALACHLOR

Chemical/Physical Properties

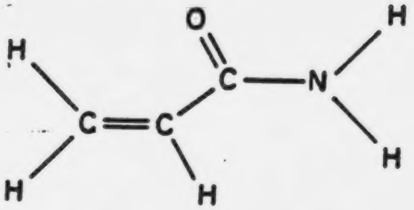
Molecular Weight:	269.77
Melting Point:	40-41 C
Vapor Pressure:	2.2×10^{-5} mm Hg at 25 C
Solubility in Water:	140 mg/L (23 C)
	242 mg/L (25 C)

Uses

Alachlor is a preemergence selective herbicide used in several crops, including soybeans, corn and peanuts. It is resistant to photodecomposition, with no ultraviolet absorption above 280 nm. The structural formula of alachlor is shown on Figure 2-1 .

ACRYLAMIDE

STRUCTURAL FORMULA

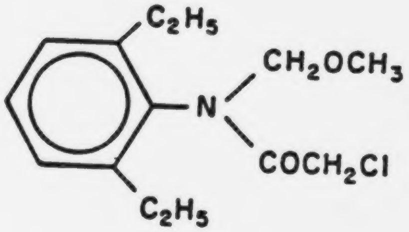


Chemical Name: 2 - Propenamide

Common/Trade Names: Propenamide, Acrylic amide, Propenoic acid amide, Ethylenecarboxamide, Akrylamid

ALACHLOR

STRUCTURAL FORMULA



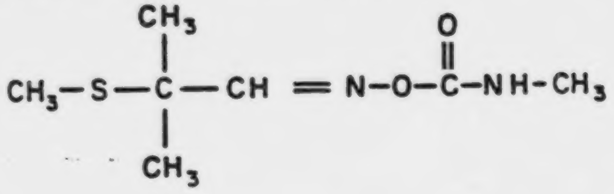
Chemical Name: 2 - Chloro - 2' 6' - diethyl - N - methoxymethylacetanilide

Common/Trade Names: Metachlor; CP 50144, Lasso, Lazo, Alanex

FIGURE 2-2

ALDICARB

STRUCTURAL FORMULA



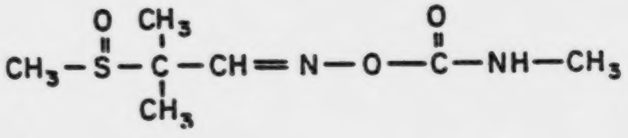
$$CH_3-S-\underset{\displaystyle CH_3}{\overset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}}-CH=N-O-\overset{\displaystyle O}{\overset{\|}{C}}-NH-CH_3$$

Chemical Name: 2 methyl -2 (methylthio) propionaldehyde -
O- (methylcarbamoyl) - oxamine

Common / Trade Names: UC 21149, Temik, Ambush

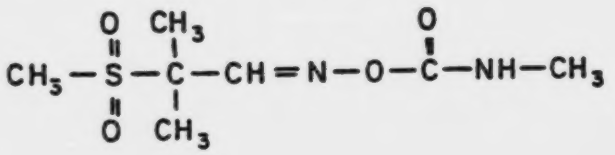
ALDICARB BREAKDOWN PRODUCTS

ALDICARB SULFOXIDE



$$CH_3-\overset{\displaystyle O}{\overset{\|}{S}}-\underset{\displaystyle CH_3}{\overset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}}-CH=N-O-\overset{\displaystyle O}{\overset{\|}{C}}-NH-CH_3$$

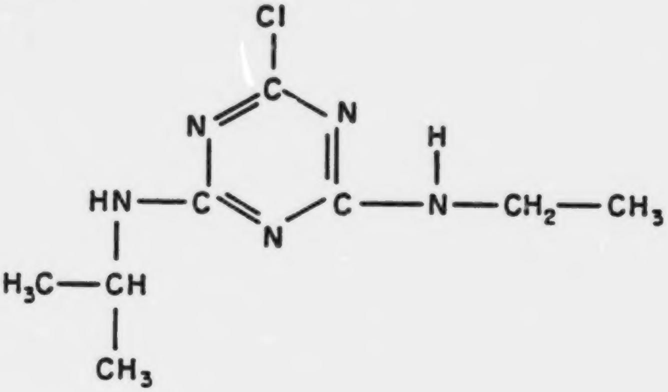
ALDICARB SULFONE



$$CH_3-\underset{\displaystyle O}{\underset{\|}{\overset{\displaystyle O}{\overset{\|}{S}}}}-\underset{\displaystyle CH_3}{\overset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}}-CH=N-O-\overset{\displaystyle O}{\overset{\|}{C}}-NH-CH_3$$

ATRAZINE

STRUCTURAL. FORMULA



Chemical Name : 2 - Chloro - 4 - ethylamino - 6 - isopropylamino S - triazine

Common / Trade Names : G - 30027®, Gesaprim ®, AAtrex®, Atranex®, Crisazine®, Vectal® SC, Atratol® A, Candex®, Fenamine®, Fenatrol®, Geigy 30, 027, Gesoprim, Hugazin®, Inakor®, Primatol, Primatol A, Primaze®, Radazin®, Strazine, Weedex® A, Zeazin®, Cekuzina® - T

CARBOFURAN

Chemical/Physical Properties

Molecular Weight:	221.3
Melting Point:	150-152 C
Vapor Pressure:	2×10^{-5} mm (33 C)
Solubility in Water:	700 mg/L (25 C)

Uses

Carbofuran is a systemic insecticide widely used to control corn rootworms. It is also used as an ascaricide and nematocide. The structural formula of carbofuran is shown on Figure 2-4.

CHLORDANE

Chemical/Physical Properties

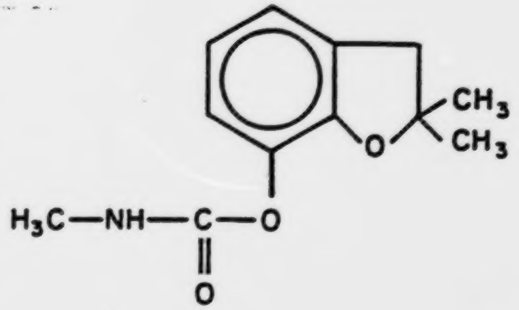
Molecular Weight:	409.8
Melting Point:	106 C
Vapor Pressure:	1×10^{-5} mm Hg (20 C)
Solubility in Water:	75 cis:25 trans mixture - 0.056 mg/L

Uses

Technical chlordane consists of 60 to 75% isomers of chlordane and 25 to 40% of related compounds including two isomers of heptachlor and one each of enneachloro and decachlorodicyclopentadiene. The solubility of technical grade chlordane has been reported as 9 ug/L. This pesticide is used against coleopterous pests, termites, wood-boring beetles, and in ant baits. The structural formula of chlordane is shown on Figure 2-4.

CARBOFURAN

STRUCTURAL FORMULA

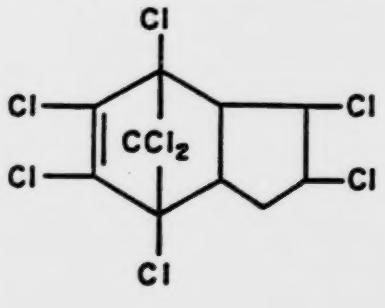


Chemical Names: 2, 3 - Dihydro - 2, 2 - dimethyl - 7 - benzo - furanol methylcarbamate; 2, 3 - Dihydro - 2, 2 - dimethyl - 7 - benzo - furanylmethylcarbamate

Common / Trade Names: furadan; NIA 10,242; ENT 27,164

CHLORDANE

STRUCTURAL FORMULA



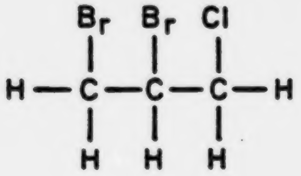
Chemical Name: 1, 2, 4, 5, 6, 7, 8, 8 - octachlor - 2, 3, 3a, 4, 7, 7a - hexahydro - 4, 7 - methano - 1 H - indene

Common / Trade Names: Chlordan®, Belt®, Chlor Kil®, Corodane®, Kypchlor®, Niran®, Octachlor®, Orthoklor®, Synklor®, Topiclor 20®, Velsicol 1068®, Chlorogran®, Prentox®, Penticklor®

FIGURE 2-5

DIBROMOCHLOROPROPANE

STRUCTURAL FORMULA



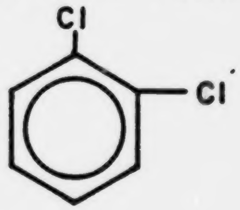
$$\begin{array}{ccccccccc} & & \mathrm{Br} & & \mathrm{Br} & & \mathrm{Cl} & & \\ & & | & & | & & | & & \\ \mathrm{H} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{H} \\ & & | & & | & & | & & \\ & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \end{array}$$

Chemical Name : 1, 2 - dibromo - 3 - chloropropane

Common/Trade Names : DBCP, Nemafume®, Nemanax ®,
Nemaset®, OS1897, Fumazone, Nemagone

o - DICHLOROBENZENE

STRUCTURAL FORMULA



Chemical Name : 1, 2 - dichlorobenzene

Common/ Trade Names : None

CIS - 1,2-DICHLOROETHYLENE

Chemical/Physical Properties

Molecular Weight:	96.95
Melting Point:	-80.5 C
Boiling Point:	60 C
Vapor Pressure:	210 mm Hg (25 C)
Solubility in Water:	800 mg/L (20 C)

Uses

Cis-1,2-Dichloroethylene is used as a solvent for fats, phenol, and camphor; it is also used to retard fermentation. Other uses are for refrigeration and as an additive to dye and lacquer solutions. The structural formula of cis-1,2-dichloroethylene is shown on Figure 2-6.

TRANS-1,2-DICHLOROETHYLENE

Chemical/Physical Properties

Molecular Weight:	96.95
Melting Point:	-50 C
Boiling Point:	48 C
Vapor Pressure:	200 mm Hg (20 C)
Solubility in Water:	600 mg/L (20 C)

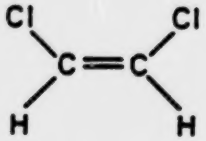
Uses

Trans-1,2-dichloroethylene is used as a solvent for fats, phenol, and camphor; it is also used to retard fermentation. Other uses are for refrigeration and as an additive to dye and lacquer solutions. The structural formula for trans-1,2-dichloroethylene is shown on Figure 2-6.

FIGURE 2-6

cis-1,2-DICHLOROETHYLENE

STRUCTURAL FORMULA

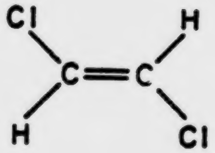


Chemical Names: cis-1,2-dichloroethylene; cis-1,2-dichloroethene

Common/Trade Names: cis-acetylenedichloride, NCI-C51581

trans-1,2-DICHLOROETHYLENE

STRUCTURAL FORMULA



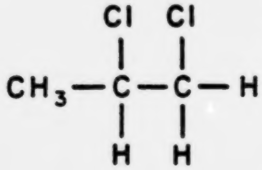
Chemical Names: trans-1,2-dichloroethylene; trans-1,2-dichloroethene

Common/Trade Name: trans-acetylenedichloride

FIGURE 2-7

1, 2 - DICHLOROPROPANE

STRUCTURAL FORMULA



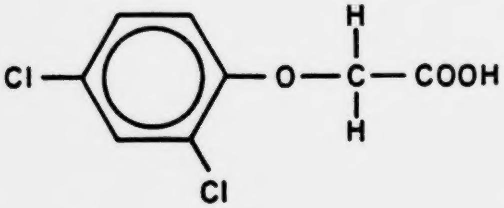
$$\begin{array}{ccccccc} & & Cl & & Cl & & \\ & & | & & | & & \\ CH_3 & - & C & - & C & - & H \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

Chemical Name : 1, 2 - dichloropropane

Common / Trade Names : propylenechloride, propylenedichloride

2, 4 - D

STRUCTURAL FORMULA



Chemical Name : (2, 4 - Dichlorophenoxy) acetic acid

Common / Trade Names : Hedonal, Innoxol

EPICHLOROHYDRIN

Chemical/Physical Properties

Molecular Weight:	92.53
Melting Point:	-26 C
Boiling Point:	116/117 C
Vapor Pressure:	12 mm Hg (20 C)
	22 mm Hg (30 C)
Solubility in Water:	60,000 mg/L (20 C)

Uses

Epichlorohydrin is used as a solvent for natural and synthetic resins, gums, cellulose, esters and ethers, paints, varnishes, nail enamels and lacquers, and as a cement for celluloid. Epichlorohydrin is also used in the manufacture of epoxy resins formed by the reaction of epichlorohydrin and bisphenol A to produce diglycidyl esters of bisphenol A. The structural formula for epichlorohydrin is presented on Figure 2-8.

ETHYLBENZENE

Chemical/Physical Properties

Molecular Weight:	106.16
Melting Point:	-95 C
Boiling Point:	136.25 C
Vapor Pressure:	7 mm Hg (20 C)
	12 mm Hg (30 C)
Solubility in Water:	140 mg/L (15 C)
	152 mg/L (20 C)

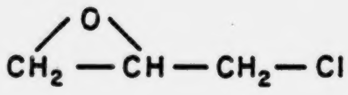
Uses

Ethylbenzene is used in the manufacture of styrene and acetophenone. It is also a constituent of asphalt and naptha. The structural formula of ethylbenzene is shown on Figure 2-8.

FIGURE 2-8

EPICHLOROHYDRIN

STRUCTURAL FORMULA

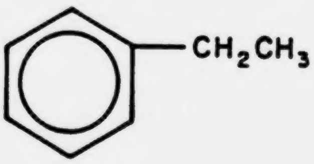


Chemical Names: 3 - Chloropropene - 1, 2 - oxide ; (Chloromethyl) oxirane ; 3 - Chloro - 1, 2 - epoxypropane ; (Chloromethyl) ethylene oxide ; α - Epichlorohydrin ; 1, - 2 - Epoxy - 3 - chloro propane ; 2, 3 - Epoxypropylchloride

Common/Trade Names: Glycerol epichlorohydrin ; NCI - C07001 ; SKEKLG ; ECH

ETHYLBENZENE

STRUCTURAL FORMULA

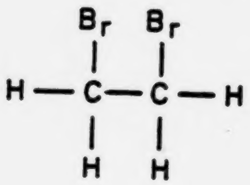


Chemical Name: ethylbenzene

FIGURE 2-9

EDB

STRUCTURAL FORMULA



$$\begin{array}{ccccccc} & & Br & & Br & & \\ & & | & & | & & \\ H & — & C & — & C & — & H \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

Chemical Name: 1,2 – Dibromoethane

Common / Trade Names: EDB, ethylene dibromide, ethylene bromide, Dowfume W 85

HEPTACHLOR

Chemical/Physical Properties

Molecular Weight: 373.53
Melting Point: 95-96 C
Vapor Pressure: 3×10^{-4} mm Hg (25 C)
Solubility in Water: 0.056 mg/L (25 C)

Uses

Heptachlor is an insecticide used on cotton for control of boll weevil and bollworms. Technical product contains 72% heptachlor and 28% related compounds. The structural formula of heptachlor is shown on Figure 2-10.

HEPTACHLOR EPOXIDE

Chemical/Physical Properties

Molecular Weight: 389.83
Melting Point: 157-160 C
Vapor Pressure: 3×10^{-4} mm Hg at 25 C
Solubility in Water: 0.350 mg/L

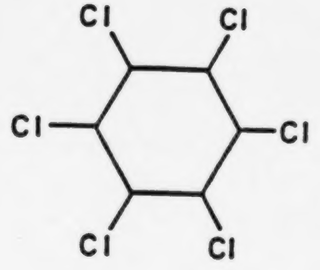
Uses

Heptachlor epoxide is a degradation product of heptachlor. The structural formula of heptachlor epoxide is shown on Figure 2-10.

FIGURE 2-11

LINDANE

STRUCTURAL FORMULA

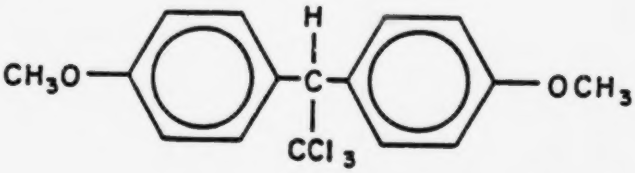


Chemical Name: gamma (γ) isomer of 1,2,3,4,5,6-Hexachlorocyclohexane

Common / Trade Names: γ-HCH, γ benzene hexachloride, gamma benzene hexachloride, gamma hexachlor, ENT 7796, Aparsin, Aphtiria, γ BHC, Gammalin, Gamene, Gamiso, Gammaexane, Gexane, Jacutin, Kwell, Lindafor, Lindatox, Lorexane, Quelada, Streunex, Tri-6, Viton

METHOXYCHLOR

STRUCTURAL FORMULA



Chemical Names: 1, 1' (2,2,2-Trichloroethylidene)-bis [4-methoxy benzene]; 1,1,1-trichloro-2,2-bis (p-methoxy-phenyl) ethane; 2,2-di-p-anisyl-1,1,1-trichloroethane

Common/Trade Names: DMDT, methoxy-DDT, Marlate

MONOCHLOROBENZENE

Chemical/Physical Properties

Molecular Weight:	112.56
Melting Point:	-46 C
Boiling Point:	132 C
Vapor Pressure:	8.8 mm Hg (20 C)
	11.8 mm Hg (25 C)
	15 mm Hg (30 C)
Solubility in Water:	500 mg/L (20 C)

Uses

Monochlorobenzene is used in the manufacture of aniline, insecticides, phenol, and chloronitrobenzene. It has also been used as a solvent for paints and as a heat transfer medium. The structural formula of monochlorobenzene is shown on Figure 2-12.

POLYCHLORINATED BIPHENYLS

Chemical/Physical Properties

	Aroclor 1242	Aroclor 1254
Molecular Weight:	258	326
Boiling Point (C):	325-366	365-390
Vapor Pressure (mm Hg @ 20 C):	0.001	0.00006
Solubility in Water (mg/L):	0.24	0.056

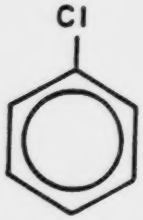
Uses

PCBs are mixtures of chlorinated biphenyls. The degree of chlorination is usually indicated by the commercial name. The Aroclor name includes a four digit number. The first two digits indicate that the mixture contains biphenyls (12), triphenyls (54), or both (25,44); the last two digits give the weight percent of chlorine in the mixture (e.g. Aroclor 1242 contains biphenyls with approximately 42 chlorine by weight). It has been reported that PCBs are soluble in water at 0.04-0.2 ppm. PCBs are used in electrical capacitors, electrical transformers, vacuum pumps, and gas-transmission turbines. PCBs were formerly used in the United States as hydraulic fluids, plasticizers, adhesives, fire retardants, wax extenders, dedusting agents, pesticide extenders, inks, lubricants, cutting oils, heat transfer systems, and in carbon-less reproducing paper. The structural formula of PCBs are shown on Figure 2-12.

FIGURE 2-12

MONOCHLOROBENZENE

STRUCTURAL FORMULA

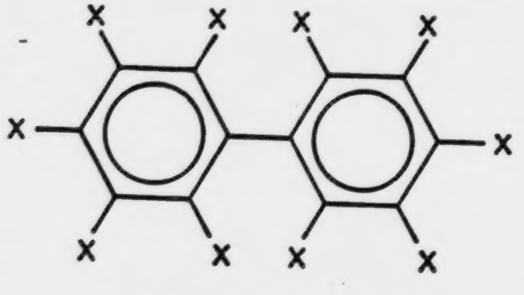


Chemical Name: chlorobenzene

Common/Trade Names: phenylchloride, benzene chloride

POLYCHLORINATED BIPHENYLS

STRUCTURAL FORMULA



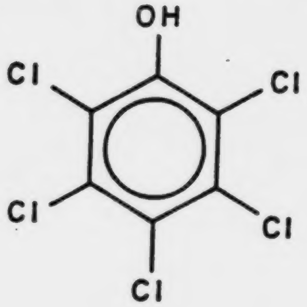
X represents H or Cl

Common/Trade Names: PCBs, chlorinated biphenyls, chlorobiphenyls, Aroclor, Clophen, Fenclor, Kanechlor, Phenochlor, Pyralene, Santotherm

PENTACHLOROPHENOL

FIGURE 2-13

STRUCTURAL FORMULA

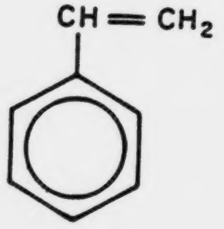


Chemical Name: Pentachlorophenol

Common/Trade Names: Dowicide 7®, DP-2 Centimicrobial, EC-7, EP 30, Fungiben, Grundier, Arbezol, Lauxtol, Lipoprem, PCP, Penchlorol, Penta, Pentacon® Penwar®, Permasan, Preventol P, Priltox, Santaphen 20®

STYRENE

STRUCTURAL FORMULA



Chemical Name: Ethenylbenzene

Common/Trade Names: Styrol, styrolene, cinnamene, cinnamol, phenylethylene, vinyl benzene

TOLUENE

Chemical/Physical Properties

Molecular Weight:	92.13
Melting Point:	-95 C
Boiling Point:	110.6 C
Vapor Pressure:	10 mm Hg (6.4 C)
	22 mm Hg (20 C)
	40 mm Hg (31.8 C)
Solubility in Water:	470 mg/L (16 C)
	515 mg/L (20 C)

Uses

Toluene is used in the manufacture of benzoic acid, benzaldehyde, medicines, dyes, perfumes, and explosives such as trinitrotoluene (TNT). It also serves as a solvent for paints, resins, gums, and PVC joints, and as a diluent and thinner in nitrocellulose lacquers. The structural formula of toluene is shown on Figure 2-14.

TOXAPHENE

Chemical/Physical Properties

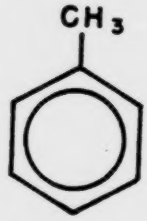
Molecular Weight:	412
Melting Point:	65-90 C
Boiling Point:	Decomposes above 120 C
Vapor Pressure:	0.2-0.4 mm Hg (20 C)
Solubility:	3 mg/L (25 C)

Uses

Toxaphene is a complex mixture of at least 175 compounds of which the structure of fewer than 10 are known. An approximate overall empirical formula is $C_{10}H_{10}Cl_8$. Toxaphene is a chlorinated camphene that is 67-69 percent chlorine. It is widely used as a foliage insecticide on a variety of food, feed, and fiber crops. The largest use is on cotton crops. Other major uses are for cattle and swine and on soy beans, corn, wheat, peanuts, lettuce, and tomatoes. The structural formula of toxaphene is shown on Figure 2-14.

TOLUENE

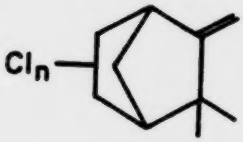
STRUCTURAL FORMULA



Chemical Name: Methylbenzene
Common/Trade Names: Phenylmethane, Tolnol
Metacide

TOXAPHENE

STRUCTURAL FORMULA



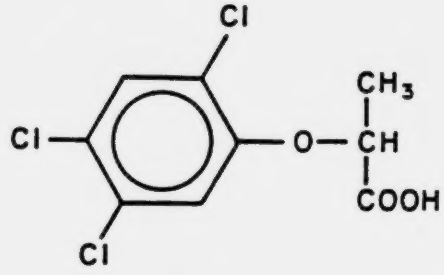
This chlorinated camphene is 67-69 per cent chlorine, where n is usually equal to 8.

Common/Trade Names: Chlorinated camphene, camphechlor, polychlorocamphene, synthetic 3956, Alltox, Geniphene, Motox, Penphene, Phenacide, Phenatox, Stroban-T, Toxakil

FIGURE 2-15

2,4,5-TP

STRUCTURAL FORMULA

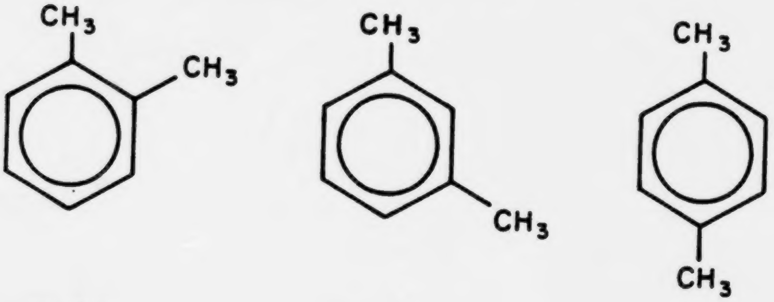

Cl
Cl
Cl
O
CH3
CH
COOH

Chemical Name: 2-(2,4,5-trichlorophenoxy) propionic acid

Common / Trade Names: Fenoprop, Garlon, Kuron, Silvex

XYLENES

STRUCTURAL FORMULA


CH3
CH3
CH3
CH3
CH3
CH3

ortho meta para

Chemical Names: o-1,2-dimethylbenzene; m-1,3-dimethylbenzene; p-1,4-dimethylbenzene

Common/Trade Name: xylol

Potential Sources of Entry

Many of the SOCs have agricultural applications and are transported into drinking water supplies by runoff and by percolation. The following SOCs have agricultural applications:

- alachlor
- aldicarb
- atrazine
- carbofuran
- chlordane
- DBCP
- 1,2-dichloropropane
- o-dichlorobenzene
- 2,4-D
- EDB
- heptachlor
- heptachlor epoxide
- lindane
- methoxychlor
- monochlorobenzene
- 2,4,5-TP
- toxaphene

Another source of contamination is industrial point discharge in the form of waste effluent, spills or leaks, or runoff from maintenance applications. The following SOCs are used as industrial, organic solvents:

- 1,2-dichloropropane
- cis-1,2-dichloroethylene
- trans-1,2-dichloroethylene
- o-dichlorobenzene
- epichlorohydrin
- monochlorobenzene
- toluene
- o-xylene

The following SOCs are used in industrial manufacturing (with the specific industries in parenthesis):

- acrylamide (polymers)
- cis-1,2-dichloroethylene (refridgerant, dye, and lacquer)
- trans-1,2-dichloroethylene (refridgerant, dye, and lacquer)
- epichlorohydrin (epoxy resins)
- ethylbenzene (styrene and acetophenone)
- monochlorobenzene (aromatics)
- PCBs (electrical)
- styrene (polymer)
- toluene (medicine, dye, and perfume)
- o-xylene (phthalic anhydride and insecticides)

M-xylene and p-xylene are components of high octane gasoline and can enter drinking water supplies as a result of gasoline spills. Pentachlorophenol is an industrial fungicide and can enter the drinking water after maintenance applications.

3. AVAILABLE TECHNOLOGIES

This section provides an overview of the various technologies which have been considered for removing the 29 SOCs from drinking water. The results of a literature review of the treatment technologies used to remove each of the 29 SOCs from drinking water are presented in Table 3-1. The level of development of each technology is indicated by the type of evaluations that have been performed: bench (B), pilot (P), and full-scale (F) testing. Bench-scale testing will generally indicate whether or not a technology is feasible; pilot testing is used in establishing feasibility and design criteria; full-scale testing provides an evaluation of the process under typical operating conditions.

Activated Carbon

Activated carbon has been used to treat all 29 SOCs, with the exception of epichlorohydrin, for which no treatability information has been found. Extensive bench-scale testing either in the form of isotherm or dynamic minicolumn testing has been performed, along with some pilot and several full-scale evaluations. Several of the full-scale installations involved either partial replacement of media filters with carbon or powdered activated carbon (PAC) addition in conjunction with coagulation/sedimentation.

Extensive testing of carbon absorption has proven it to be effective in the removal of most of the SOCs. Therefore, it can be regarded as the most applicable technology in removing SOCs from drinking water.

Aeration

Aeration has been used to treat 15 of the 29 SOCs, mostly in pilot-scale testing of air stripping equipment. These compounds represent the more volatile SOCs, many of which are chlorinated solvents.

In several of the full-scale evaluations, the SOC removal has been incidental as these units were not specifically designed for SOC removal. Aeration has been shown to be effective in removing volatile SOCs and should thus be considered as an applicable technology. However, transfer of SOCs

TABLE 3-1

SUMMARY OF TREATMENT DATA FOR THE 29 SOCs

	Activated Carbon	Aeration	Reverse Osmosis	Oxidation	Conventional Treatment
Acrylamide	B		B		B
Alachlor	B,F	B		B	B, F
Aldicarb	P,F				
Aldicarb Sulfone	P,F				
Aldicarb Sulfoxide	P,F				
Atrazine	B,F	B	B	B	B, F
Carbofuran	B,P	B	B	B	B, F
Chlordane	B,P,F				
DBCP	B,P,F	P			
1,2-Dichloropropane	B,P	B,P	B	B	
cis-1,2-Dichloroethylene	B,P,F	B,P	B	B	
trans-1,2-Dichloroethylene	B,P	B,P,F	B	B	
o-Dichlorobenzene	B,F	B,P	B	B	
2,4-D	B,P		B	B	B
EDB	B,P,F	B,P	B	B	
Epichlorohydrin					
Ethylbenzene	B	B,P,F	B	B	
Heptachlor	B,F			B	
Heptachlor epoxide	B			B	B
Lindane	B,P,F		B,P	B	B, P
Methoxychlor	B,F		P	B	
Monochlorobenzene	B,P	B	B	B	
PCBs	B,P,F	F		P	
Pentachlorophenol	B,P,F				
Styrene	B	F		B	
Toluene	B,P	B,P	B	B	F
2,4,5-TP	B			B	
Toxaphene	B,F				B,F
o-Xylene	B	B,P,F	B	B	F
m-Xylene	B	B,P,F	B	B	F
p-Xylene	B,F	B,P,F	B	B	F

Note:

"B" denotes treatment data available from bench-scale testing.
"P" denotes treatment data available from pilot-scale testing.
"F" denotes treatment data available from full-scale testing.
o-xylene, m-xylene and p-xylene are counted as one compound (total xylenes)

Conventional Treatment

Conventional treatment (coagulation/sedimentation/filtration) has been used to treat 10 SOCs, six of which have been evaluated in full-scale installations. The removals for most of the SOCs have been poor, typically less than 10 percent removal. It should also be noted that influent concentrations in much of this testing have been very low, typically less than 5 ug/L.

Since conventional treatment is of limited effectiveness in removing SOCs, it should be considered as an additional technology of limited applicability.

Summary of Available Technologies

Based on the review of treatment data for the 29 SOCs, the available technologies have been divided into the three general categories as follows:

Most Applicable Technologies

Granular Activated Carbon

Other Applicable Technologies

Packed Column Aeration

Additional Technologies

Powdered Activated Carbon (PAC)
Diffused Aeration
Oxidation
Reverse Osmosis
Conventional Treatment

More detailed descriptions of each of these technologies and their removal efficiencies for the 29 SOCs are presented in the following sections.

4. MOST APPLICABLE TECHNOLOGY - GRANULAR ACTIVATED CARBON

Most applicable technologies are those technologies which have demonstrated highly effective capacities to remove the 29 SOCs, and for which reasonable cost estimates can be developed for a wide range of influent/effluent conditions. As indicated in Section 3, the only technology which is considered to be most applicable for all of the 29 SOCs is granular activated carbon (GAC) adsorption. According to the 1986 amendments to the Safe Drinking Water Act, Congress specified in Section 1412(b)(5) of the Act that:

> Granular activated carbon is feasible for the control of synthetic organic chemicals, and any technology, treatment technique, or other means found to be the best available for the control of synthetic organic chemicals must be at least as effective in controlling synthetic organic chemicals as granular activated carbon.

The use of GAC for drinking water treatment in the United States has been limited to primarily taste and odor control applications. However, since the widespread detection of organics in drinking water supplies, much research and many pilot-scale studies have been undertaken to evaluate the effectiveness of GAC for controlling organic compounds. Based on past research and pilot-scale work, GAC represents one unit process with the ability to remove a broad spectrum of organic chemicals from water. Although GAC is considered to be the best available broad spectrum removal process, it exhibits a wide range of effectiveness in adsorbing organic compounds.

Process Description

The application of granular activated carbon adsorption for removing organic compounds from drinking water supplies involves the following major process design considerations:

- Carbon Usage Rate - pounds of carbon per volume of water treated
- Empty Bed Contact Time
- Pretreatment
- Contactor Configuration - downflow versus upflow, pressure versus gravity, single-stage versus multi-stage or parallel versus series

when the carbon bed life is long. Disinfection with chlorine prior to GAC adsorption should be avoided because chlorine by-products formed during the reduction of chlorine on GAC are adsorbed by carbon, and therefore, compete with the organics for adsorption sites. In addition, if carbon regeneration is anticipated, adsorption of these byproducts could possibly result in the formation of hazardous substances during regeneration processes. Filtration ahead of the GAC system is a common solution to prevent clogging of the bed. GAC systems are sometimes added to the end of a conventional treatment process.

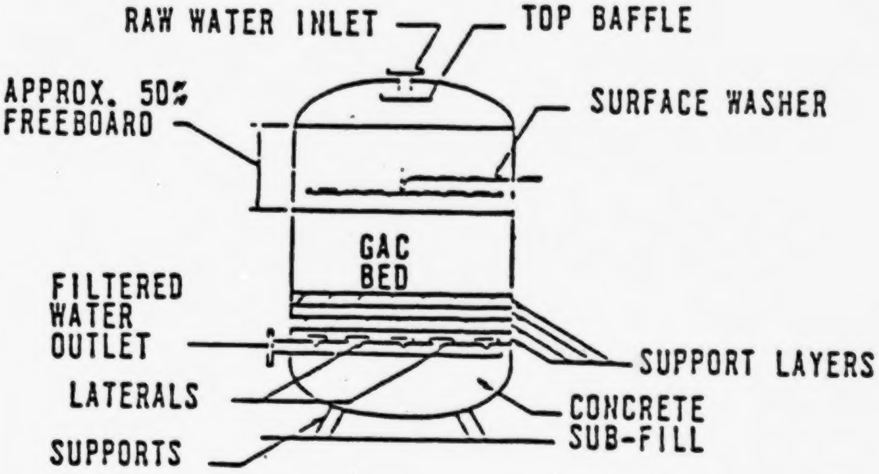
When the background organic levels in the raw water are high, the carbon is used at a faster rate, necessitating more frequent replacement. This increases the operating cost of the system. Pretreatment can be provided to reduce the organic loading on the carbon, thereby decreasing the carbon usage rate. The need for pretreatment should, however, be justified on the basis of costs. Examples of processes which may be used for pretreatment include conventional treatment, ozonation, and packed column aeration.

Contactor Configuration

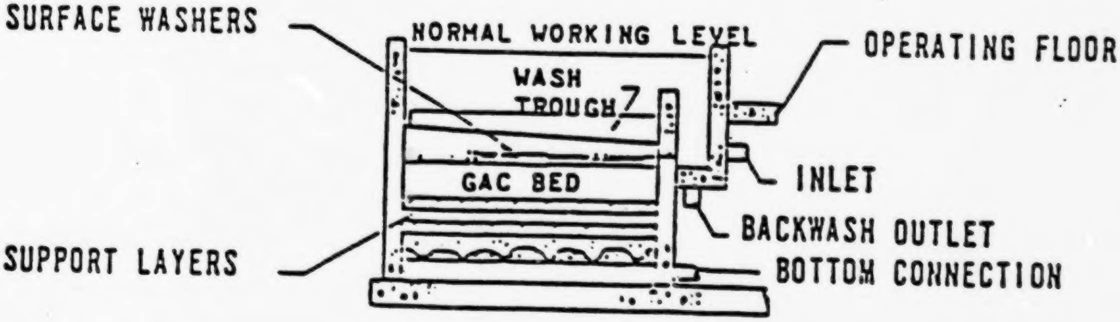
Based on the estimates of carbon usage rate and contact time, a conceptual process design can be developed by evaluating various contactor configurations. The two basic modes of contactor operation are upflow and downflow. Upflow expanded bed contactors allow suspended solids to pass through the bed without producing a high pressure drop. This configuration is not generally considered for use in water treatment where the level of suspended solids is relatively low. Downflow fixed bed contactors offer the simplest and most common contactor configuration for SOC removal from drinking water. These contactors can be operated either under pressure or by gravity.

The choice of pressure or gravity is generally dependent upon the hydraulic constraints of a given system. Pressure contactors may be more applicable to ground water systems because pumping of the ground water is required. Gravity contactors are generally more suitable for surface water systems if sufficient head is available. Gravity contactors, when used, will typically be placed downstream of surface water filtration systems. Diagrams of pressure and gravity systems are presented on Figure 4-1.

FIGURE 4-1


RAW WATER INLET
TOP BAFFLE
APPROX. 50% FREEBOARD
SURFACE WASHER
GAC BED
FILTERED WATER OUTLET
SUPPORT LAYERS
LATERALS
CONCRETE SUB-FILL
SUPPORTS

PRESSURE CONTACTOR


SURFACE WASHERS
NORMAL WORKING LEVEL
OPERATING FLOOR
WASH TROUGH
GAC BED
INLET
BACKWASH OUTLET
SUPPORT LAYERS
BOTTOM CONNECTION

GRAVITY CONTACTOR

SCHEMATICS OF CARBON CONTACTORS

the free water is removed and returned for treatment. The drained carbon is then manually drummed and shipped for landfill or incineration.

The advantages to off-site disposal lie mainly in its technical simplicity; and, as such, it is a sound approach for applications with relatively small carbon usage rates (generally less than 500 pounds per day). The need to dispose of the spent carbon, however, is a concern especially since toxic or hazardous materials are adsorbed on the spent carbon. Incineration of the spent carbon to ensure proper ultimate disposal may become necessary.

The off-site regeneration approach is somewhat similar to the throwaway concept from a carbon handling standpoint; however, off-site regeneration begins to assume some of the economies associated with on-site regeneration. However, the number of handling steps and resulting carbon attrition and loss are a major disadvantage when compared to other alternatives. The off-site reactivation approach has generally proven most cost effective in applications where the carbon usage rate falls in the 500 to 2,000-pound per day range (Kornegay, 1979).

GAC Equipment

The major equipment typically found in a GAC installation includes:

- Carbon Contactors - either common wall concrete or lined steel vessels. In either case, provisions for underdrainage, backwashing, and removing the spent carbon must be made.
- Carbon Storage - additional storage facilities may be required for handling of virgin, regenerated and spent carbon, depending upon the size and type of facility.
- Carbon Transport Facilities - includes piping, valves, and pumps.
- Carbon Fill - the actual initial carbon charge depends on the type and volume of carbon required for treatment.

Having outlined the GAC process and the pertinent design criteria, brief descriptions of the testing methods and SOC removal case studies are presented below.

pulverized carbon in a fixed volume of aqueous solution of known SOC concentration and agitating over a sufficient time to reach equilibrium. The resultant liquid-phase SOC concentration is then measured and the equilibrium capacity (or loading) is calculated from the amount of SOC adsorbed and the known weight of carbon in solution. These steps are repeated for a series of known weights of carbon for a given initial SOC concentration. The relationship between equilibrium capacity and equilibrium liquid-phase concentration has been found to generally follow the Freundlich isotherm relationship:

$$X/M = KC^{1/n}$$

where:

X/M = equilibrium capacity (mg SOC/g carbon)
X = amount of SOC adsorbed from solution (mg/L)
M = weight of carbon (g/L)
K = capacity at 1 mg/L SOC concentration
C = SOC equilibrium concentration (mg/L)
1/n = exponent

K and 1/n are typically referred to as Freundlich constants. K is related to the adsorption capacity of GAC for an SOC, and 1/n is one indicator of the adsorption intensity. The following equation, derived from the Freundlich equation and a mass balance for column operation, can be used to estimate carbon usage rates in pounds of carbon per thousand gallons of water treated:

$$\text{Carbon usage (lbs/1,000 gal)} = \frac{C}{K(C)^{1/n}} \times 8.34$$

where:

C = SOC influent concentration to column (mg/L)
K, 1/n = Freundlich isotherm parameters
8.34 = conversion factor from g/liter to lbs./1,000 gal

A sample calculation using this method is shown in Appendix A. This method assumes that a GAC system is operated until the SOC concentration in the effluent equals that of the influent, i.e., the GAC is in equilibrium with the untreated contaminant concentration. Thus, the carbon usage rate calculated in this manner represents the maximum amount of SOC adsorbed per unit weight of carbon for the existing water quality conditions.

TABLE 4-1

GAC ISOTHERM CONSTANTS FOR SOCs[1,2,3]

SOC	Mol. Wt.	Carbon Type[4]	pH	1/n	K $(\text{umole/g})(\text{L/umole})^{1/n}$	K $(\text{mg/g})(\text{L/mg})^{1/n}$
Alachlor	269.8	F4	6.20	0.26	1275.0	483.55
Aldicarb	190.3	F4	6.3-6.6	0.40	360.0	133.01
Atrazine	215.7	F4	7.60	0.36	787.0	294.88
Carbofuran	221.3	F4	4.30	0.41	673.0	276.41
Chlordane	409.8	F3/F4	5.30	0.33	346.0	190.33
cis-1,2-Dichloroethylene	97.0	F4	6.6-8.0	0.59	30.5	11.72
DBCP	236.4	F4	6.2-6.6	0.51	465.0	229.35
o-Dichlorobenzene	147.0	F4	5.6-5.8	0.38	865.0	263.49
1,2-Dichloropropane	113.0	F4	6.1-7.3	0.59	46.6	19.06
2,4-D	221.0	ANA/F4	-	0.27	194.0	64.46
Ethyl benzene	106.2	F4	5.6-6.9	0.53	507.0	176.69
EDB	187.9	F4	6.2-7.1	0.46	53.9	21.85
Heptachlor	373.5	F3/F4	-	0.92	1110.0	1025.91
Heptachlor Epoxide	389.8	F3/F4	-	0.75	2020.0	1596.14
Lindane	290.9	F4	4.2-6.9	0.43	606.0	299.75
Methoxychlor	345.7	NS/F4	-	0.36	223.0	112.99
Monochlorobenzene	112.6	F4	6.50	0.35	418.0	101.06
PCB (Aroclor 1254)	326.0	F4	7.00	1.03	13270.0	13723.80
Pentachlorophenol	266.4	F4	4.6-6.8	0.34	1062.0	443.53
Silvex	255.5	F4	7.00	0.38	479.0	205.55
Styrene	104.0	F4	9.40	0.48	1083.0	333.80
Tetrachloroethylene	165.8	F4	5.1-7.6	0.52	341.2	142.98
Toluene	92.1	F4	4.6-6.7	0.45	356.0	95.91
Toxaphene	412.0	F4	7.00	0.74	1182.0	938.62
trans-1,2-Dichloroethylene	97.0	F4	6.3-6.7	0.45	50.5	13.99
o-Xylene	106.2	F4	6.3-6.45	0.47	603.0	183.69
m-Xylene	106.2	F4	6.70	0.75	410.0	234.03
p-Xylene	106.2	F4	6.90	0.42	740.0	201.51

Notes:

"-" = Not Reported

1. Source: Miltner (1987a), (1987b)
2. Data not available for acrylamide, aldicarb sulfone, or aldicarb sulfoxide
3. For distilled water at room temperature
4. Carbon type legend:

F4 = Filtrasorb 400
F3 = Filtrasorb 300
ANA = Aqua Nuchar A
NS = Nuchar Special

TABLE 4-2

CARBON USAGE RATES^{1,2}

Compound Name		Carbon Usage (lbs/KGal)								
Alachlor	Inf (ug/L)		10.00			50.00			100.00	
	Eff (ug/L)	0.60	2.00	6.00	0.60	2.00	6.00	0.60	2.00	6.00
	Usage Rate	0.000611	0.000597	0.000573	0.00206	0.00202	0.00199	0.00346	0.00341	0.00336
Aldicarb	Inf (ug/L)		50.00			100.00			500.00	
	Eff (ug/L)	1.30	10.00	20.00	1.30	10.00	20.00	1.30	10.00	20.00
	Usage Rate	0.0113	0.0109	0.0106	0.0172	0.0168	0.0165	0.0458	0.0453	0.0447
Atrazine	Inf (ug/L)		5.00			50.00			100.00	
	Eff (ug/L)	1.00	3.00	5.00	1.00	3.00	5.00	1.00	3.00	5.00
	Usage Rate	0.000996	0.000950	---	0.00451	0.00445	0.00442	0.00706	0.00700	0.00696
Carbofuran	Inf (ug/L)		20.00			50.00			100.00	
	Eff (ug/L)	5.00	40.00	50.00	5.00	40.00	50.00	5.00	40.00	50.00
	Usage Rate	0.00315	---	---	0.00555	0.00493	---	0.00847	0.00796	0.00786
Chlordane	Inf (ug/L)		5.00			10.00			50.00	
	Eff (ug/L)	0.50	2.00	5.00	0.50	2.00	5.00	0.50	2.00	5.00
	Usage Rate	0.00136	0.00130	---	0.00220	0.00212	0.00204	0.00667	0.00650	0.00636
cis-1,2-Dichloroethylene	Inf (ug/L)		50.00			100.00			200.00	
	Eff (ug/L)	5.00	70.00	100.00	5.00	70.00	100.00	5.00	70.00	100.00
	Usage Rate	0.223	---	---	0.300	0.272	---	0.402	0.379	0.371
DBCP	Inf (ug/L)		2.00			5.00			20.00	
	Eff (ug/L)	0.10	0.20	1.00	0.10	0.20	1.00	0.10	0.20	1.00
	Usage Rate	0.00188	0.00186	0.00176	0.00300	0.00299	0.00296	0.00600	0.00598	0.00582
o-Dichlorobenzene	Inf (ug/L)		100.00			700.00			1000.00	
	Eff (ug/L)	50.00	600.00	800.00	50.00	600.00	800.00	50.00	600.00	800.00
	Usage Rate	0.00766	---	---	0.0268	0.0243	---	0.0336	0.0316	0.0307
1,2-Dichloropropane	Inf (ug/L)		10.00			50.00			100.00	
	Eff (ug/L)	2.00	5.00	10.00	2.00	5.00	10.00	2.00	5.00	10.00
	Usage Rate	0.0702	0.0669	---	0.142	0.139	0.136	0.190	0.187	0.184
2,4-D	Inf (ug/L)		50.00			100.00			500.00	
	Eff (ug/L)	5.00	70.00	100.00	5.00	70.00	100.00	5.00	70.00	100.00
	Usage Rate	0.0152	---	---	0.0255	0.0239	---	0.0843	0.0813	0.0807

TABLE 4-2 (Continued)

Compound Name		Carbon Usage (lbs/KGal)								
Ethyl benzene	Inf (ug/L)		100.00			700.00			1000.00	
	Eff (ug/L)	50.00	700.00	800.00	50.00	700.00	800.00	50.00	700.00	800.00
	Usage Rate	0.0163	---	---	0.0436	---	---	0.0520	0.0464	0.0449
EDB	Inf (ug/L)		0.50			10.00			50.00	
	Eff (ug/L)	0.01	0.05	1.00	0.01	0.05	1.00	0.01	0.05	1.00
	Usage Rate	0.00672	0.00659	---	0.0342	0.0341	0.0332	0.0821	0.0820	0.0809
Heptachlor[3]	Inf (ug/L)		0.10			1.00			10.00	
	Eff (ug/L)	0.03	0.40	1.00	0.03	0.40	1.00	0.03	0.40	1.00
	Usage Rate	0.00389	---	---	0.00468	0.00468	---	0.00562	0.00562	0.00562
Heptachlor epoxide	Inf (ug/L)		0.10			1.00			10.00	
	Eff (ug/L)	0.03	0.20	1.00	0.03	0.20	1.00	0.03	0.20	1.00
	Usage Rate	0.000572	---	---	0.00116	0.00106	---	0.00212	0.00209	0.00197
Lindane	Inf (ug/L)		0.50			1.00			10.00	
	Eff (ug/L)	0.02	0.20	1.00	0.02	0.20	1.00	0.02	0.20	1.00
	Usage Rate	0.000408	0.000380	---	0.000612	0.000583	---	0.00228	0.00227	0.00221
Methoxychlor	Inf (ug/L)		260.00			400.00			1000.00	
	Eff (ug/L)	100.00	400.00	500.00	100.00	400.00	500.00	100.00	400.00	500.00
	Usage Rate	0.0321	---	---	0.0430	---	---	0.0793	0.0757	0.0747
Monochlorobenzene	Inf (ug/L)		100.00			600.00			1000.00	
	Eff (ug/L)	60.00	100.00	400.00	60.00	100.00	400.00	60.00	100.00	400.00
	Usage Rate	0.0185	---	---	0.0618	0.0613	0.0588	0.0866	0.0861	0.0838
PCB (Aroclor 1254)[3]	Inf (ug/L)		5.00			10.00			50.00	
	Eff (ug/L)	0.05	0.50	5.00	0.05	0.50	5.00	0.05	0.50	5.00
	Usage Rate	0.000710	0.000710	---	0.000698	0.000698	0.000698	0.000665	0.000665	0.000665
Pentachlorophenol	Inf (ug/L)		50.00			500.00			1000.00	
	Eff (ug/L)	20.00	200.00	400.00	20.00	200.00	400.00	20.00	200.00	400.00
	Usage Rate	0.00266	---	---	0.0128	0.0122	0.0115	0.0205	0.0196	0.0192
2,4,5-TP (Silvex)	Inf (ug/L)		50.00			100.00			500.00	
	Eff (ug/L)	5.00	50.00	100.00	5.00	50.00	100.00	5.00	50.00	100.00
	Usage Rate	0.00704	---	---	0.0110	0.0103	---	0.0303	0.0294	0.0289

TABLE 4-2 (Continued)

Compound Name		Carbon Usage (lbs/KGal)								
Styrene	Inf (ug/L)		10.00			50.00			200.00	
	Eff (ug/L)	2.00	5.00	20.00	2.00	5.00	20.00	2.00	5.00	20.00
	Usage Rate	0.00238	0.00231	---	0.00566	0.00557	0.00539	0.0119	0.0117	0.0115
Tetrachloroethylene	Inf (ug/L)		50.00			100.00			500.00	
	Eff (ug/L)	1.00	5.00	50.00	1.00	5.00	50.00	1.00	5.00	50.00
	Usage Rate	0.0151	0.0147	---	0.0214	0.0208	0.0195	0.0471	0.0469	0.0447
Toluene	Inf (ug/L)		500.00			3000.00			5000.00	
	Eff (ug/L)	100.00	2000.00	3000.00	100.00	2000.00	3000.00	100.00	2000.00	3000.00
	Usage Rate	0.0617	---	---	0.170	0.158	---	0.226	0.215	0.211
Toxaphene	Inf (ug/L)		5.00			10.00			50.00	
	Eff (ug/L)	1.00	5.00	10.00	1.00	5.00	10.00	1.00	5.00	10.00
	Usage Rate	0.00280	---	---	0.00365	0.00278	---	0.00614	0.00554	0.00509
trans-1,2-Dichloroethylene	Inf (ug/L)		50.00			200.00			500.00	
	Eff (ug/L)	5.00	100.00	200.00	5.00	100.00	200.00	5.00	100.00	200.00
	Usage Rate	0.120	---	---	0.261	0.248	---	0.435	0.420	0.414
m-Xylene	Inf (ug/L)		10000.00			20000.00			50000.00	
	Eff (ug/L)	1000.00	10000.00	15000.00	1000.00	10000.00	15000.00	1000.00	10000.00	15000.00
	Usage Rate	0.0742	---	---	0.0913	0.0765	0.0705	0.118	0.106	0.102
o-Xylene	Inf (ug/L)		10000.00			20000.00			50000.00	
	Eff (ug/L)	1000.00	10000.00	15000.00	1000.00	10000.00	15000.00	1000.00	10000.00	15000.00
	Usage Rate	0.163	---	---	0.238	0.225	0.217	0.392	0.377	0.373
p-Xylene	Inf (ug/L)		10000.00			20000.00			50000.00	
	Eff (ug/L)	1000.00	10000.00	15000.00	1000.00	10000.00	15000.00	1000.00	10000.00	15000.00
	Usage Rate	0.169	---	---	0.252	0.238	0.230	0.433	0.418	0.413

Notes:

1. Model-predicted carbon usage rates developed through application of CPHSDM to distilled-water isotherm study results and were adopted from:
   (a) Miltner, R.J. et al. Final Internal Report On Carbon Use Rate Data. ODW - U.S. EPA, Cincinnati, OH, June 30, 1987.
   (b) Miltner, R.J. et al. Interim Internal Report On Carbon Use Rate Data. ODW - U.S. EPA, Cincinnati, OH, June 30, 1987.

2. Distilled-water isotherm constants not available for Acrylamide, Aldicarb sulfone, Aldicarb sulfoxide, and Epichlorohydrin

3. Isotherm-predicted carbon usage rates developed through application of Freundlich's equation, as shown in Appendix A.

Region	K (mg/g) $[(L/mg)^{1/n}]$
Strong	> 500
Moderate	100-500
Weak	< 100

While adsorption isotherms are useful for obtaining preliminary data concerning adsorbability of SOCs, they have certain drawbacks that limit their applicability:

- Isotherm tests cannot be reliably used for GAC facility scale-up since the test does not provide any information on the dynamics of column operation.

Multicomponent isotherms can be conducted to describe the competitive interactions in a mixture. Since the mass transfer zones of various compounds seperate with respect to their adsorbability (chromatographic effect), multicomponent isotherme cannot predict the capacities observed in fixed-bed operation.

As a result, bench-scale or pilot-scale tests are usually required to develop the necessary design criteria.

Mini Column Tests

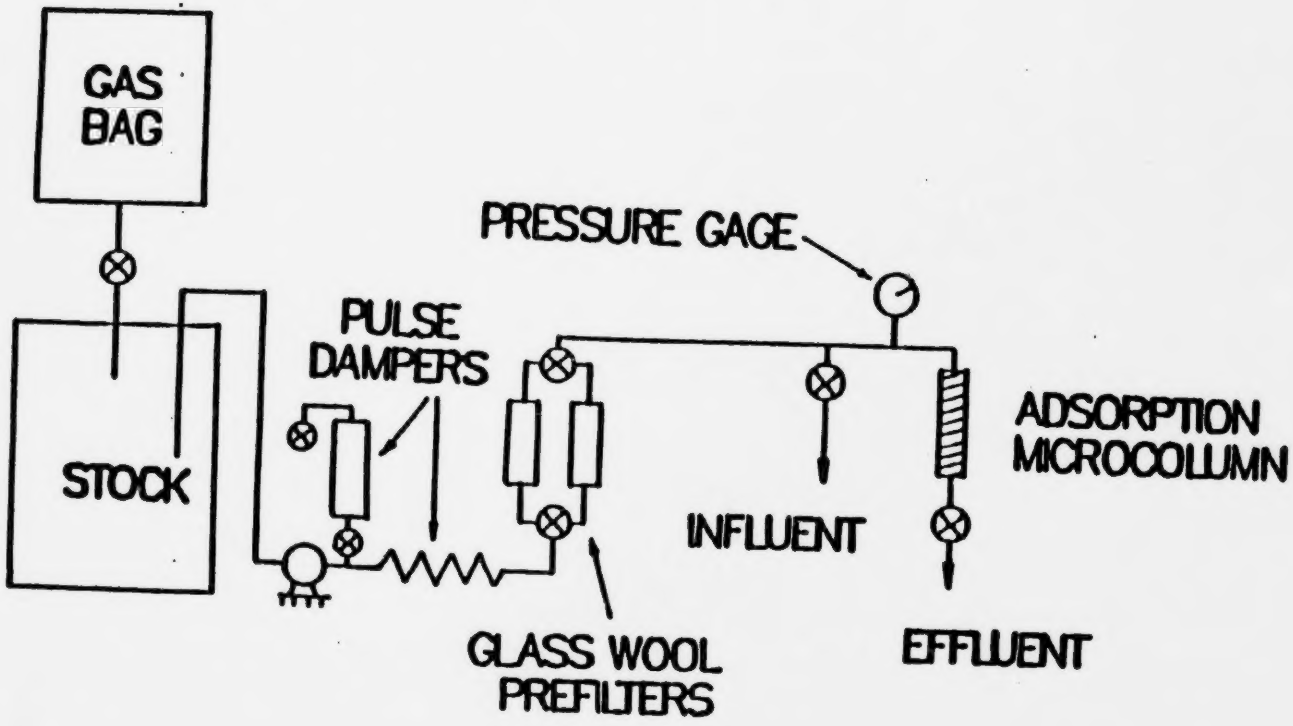
Minicolumn tests are conducted in an attempt to simulate the operation of a full-scale GAC adsorption system. Minicolumn tests are used for the following:

- Determine the feasibility of carbon treatment for a given water
- Estimate carbon usage rates
- Develop preliminary process design criteria
- Provide preliminary estimate of system economics

A limited number of column studies have been conducted to evaluate the removal of SOCs from drinking water. A typical minicolumn apparatus is illustrated on Figure 4-2. Water spiked with the specific compounds is passed through the column and the effluent is monitored to obtain a breakthrough curve.

Environmental Science and Engineering, Inc. (ESE, 1981) used a microcolumn measuring 2.25 mm in diameter and 70 mm long to study the removal of several synthetic organic chemicals by granular activated carbon. The carbon was sieved to a particle size of 200 x 325-mesh. Three separate sets of tests were performed to determine carbon usage rates for dibromochloropropane (DBCP), ethylene dibromide (EDB) (ESE, 1983), and monochlorobenzene (ESE, 1981).

FIGURE 4-2


GAS BAG
STOCK
PULSE DAMPERS
GLASS WOOL PREFILTERS
PRESSURE GAGE
INFLUENT
ADSORPTION MICROCOLUMN
EFFLUENT

TYPICAL MINI-COLUMN SETUP

concentration. Therefore, results from minicolumn studies in which pulverized carbon is used may not be suitable for scale-up to a full-scale GAC system. Also, since the length of the test is very short, generally on the order of several days, minicolumn tests do not account for possible biological effects and preadsorption of background TOC. For these reasons, it is generally recommended that mini-column scale-up be verified with pilot or full-scale studies until more research is available in these areas.

Pilot-Scale Tests

Before a full-scale GAC system is installed, preliminary on-site analysis should be performed on the water of concern. Pilot-scale tests may be used for this purpose. The empty bed contact time and the carbon usage rates are the important design criteria obtained from a field pilot study. Additional design criteria that can be developed from a pilot-study include:

- Bed depth
- Effect of hydraulic loading
- Number of contactors required
- Contactor configuration
- Carbon type
- Carbon life/replacement frequency
- System economics

Case-studies of pilot-scale testing for SOC removal from drinking water are listed below.

USEPA-DWRD - The U.S. Environmental Protection Agency's Drinking Water Research Division (USEPA-DWRD) conducted several pilot-scale studies to determine the effectiveness of carbon adsorption for the removal of cis-1,2-dichloroethylene and other industrial solvents (such as trichloroethylene and 1,1,1-trichloroethane). Love and Eilers (1982) summarized these studies and results of other work dealing with the removal of solvents from drinking water.

Contaminated wells in New Hampshire and Connecticut contained a mixture of solvents with total organic chemical (TOC) concentrations ranging from 0.3 to 0.7 mg/L. The USEPA-DWRD installed pilot-scale carbon adsorption columns 1.5 inches in diameter containing 30 inches of GAC. In the New Hampshire study, cis-1,2-dichloroethylene was also present at an average concentration of 6 ug/L. Trichloroethylene was also present at concentrations ranging from 120 to 276 ug/L. The effluent concentrations of all contaminants were below

	Average Influent Concentration (ug/L)				Volume(1) Treated (gal)	Carbon(1) Usage Rate (lb/1,000gal)
Location	Aldicarb	Carbofuran	Oxamyl	Dacthal		
1	21	3	-	-	28,000	1.04
2	105	25	-	-	53,500	0.54
3	53	42	-	-	112,500	0.26
4	262	9	15	-	26,000	1.12
5	105	24	-	-	82,700	0.35
6	151	57	-	445	21,000	1.38
7	64	25	26	-	74,000	0.39
8	36	-	-	-	51,500	0.56

Note:

1. Based on effluent concentration of 7 ug/l aldicarb.

Gulf South Research Institute - Commercially available home water treatment systems were tested under a USEPA contract to compare the efficiency of more than 30 units in removing synthetic organic chemicals. Bell et al. (1984) described results for ten units that were tested with a spiked surface water containing chlordane (50 ug/l), p-dichlorobenzene (10 ug/L), and hexachlorobenzene (10 ug/L). The home units were tested at the rated capacity as specified by the manufacturer and the average percent reduction was reported for the beginning and end of the test. Results from the seven units which provided an initial 99 percent reduction of hexachlorobenzene are presented below. The other four units achieved less than 85 percent hexachlorobenzene removal at the beginning of the test.

usage rates could not be calculated because PCB breakthrough had not occurred, however, the actual usage was less than 0.1 lb/1,000 gal.

Lake Constance, Switzerland - A pilot-scale column filled with GAC to a depth of 75 cm was tested to treat Lake Constance water spiked with 50 ug/L lindane. Morgeli (1972) reported that three different carbons were used in the column for 16-hour tests at a flow through velocity of 15 m/hr (49.2 ft/hr). The effluent lindane concentrations for the three carbons were 0.023, 2.6, and 0.08 ug/L.

ThunderBay, Ontario - Jank (1980) reported on the performance of a pilot-scale carbon column used to remove pentachlorophenol (PCP) from the effluent of the Abitibi-Northern Wood Preservers Limited activated sludge wastewater treatment plant in Thunder Bay, Ontario. The carbon system consisted of three columns measuring 100 mm in diameter and three meters in length. The columns each contained 6.8 kg (15.0 lb) of Filtrasorb 400 and were preceded by a sand filter containing an 11 kg (24.2 lb) top layer of anthracite filtering media. The carbon column reduced PCP concentrations from 3.6 to 0.03 mg/L, as shown below. No additional PCP breakthrough had occurred after 42 days of operation.

Stream	PCP Concentration mg/L	TOC mg/L
Biological System Influent	8.4	768
Activated Sludge Effluent	3.6	52
Carbon System Influent	3.4	54
Carbon System Effluent	0.03	13

Lathrop, California - The Occidental Chemical Company (Canonie Services, 1981) conducted pilot-scale studies to determine the effectiveness of granular activated carbon in treating ground water contaminated with organics. The two columns each had a diameter of 14 inches and a height of 96 inches containing four cubic feet of 12 x 40 mesh carbon. The influent contained a combination of EDB, DBCP and sulfolane. The results of this study are presented below.

	Concentration (ug/L)			
Contaminant	Influent	Effluent	Volume Treated (L)	Carbon Usage Rate (lb/1,000 gal)
EDB	9.1-10.8	<1	>654,900	<0.69
DBCP	1,400-1,500	10	302,800	1.5
Sulfolane*	2,000-3,000	1,800	151,400	3

* Date presented for equilibrium condition

diameter of 3.5 feet and a height of 6.7 feet and contains 2 ft. of anthracite on top of a 1.5 ft. thick layer of red flint sand. Each carbon column has a diameter of 7 feet and a height of 8.7 feet and contains 1,230 pounds of 18 x 40 mesh GAC. The treatment capacity of the system is 300,000 gpd.

Over a two year period, the trailer system responded to six incidents, four of which were spills of one or more synthetic organic chemicals. Lafornara (1978) reported the details of each incident and the cleanup operations which utilized the Hazardous Materials Spills Treatment trailer.

Polychlorinated biphenyls (PCB) Spill - Seattle, Washington - A spill of 265 gallons of PCB into the Duwamish Waterway occurred when an electrical transformer was dropped while being loaded onto a commercial barge. The PCBs formed pools at the bottom of the waterway. The PCB material was pumped through presettling tanks and the supernatant water was treated with the trailer's mixed media filters in series with the carbon adsorption columns. An EBCT of 30 to 40 minutes was provided. A total of 600,000 gallons of water, containing approximately PCB concentrations of 400 ug/L, were treated. The mixed-media filters reduced the PCB concentration to 3 ug/L while the PCB concentration in the activated carbon effluent was below detectable limits (0.075 ug/L).

Toxaphene Incident - The Plains, Virginia - Toxaphene was dumped into a privately-owned pond in The Plains, Virginia. The spring-fed pond was located at the head waters of Broad Run, a tributary to the Manassasus Reservoir, which serves as the source of water supply for 40,000 people. The pond was approximately 100 feet by 100 feet with a maximum depth of 7.5 feet. The toxaphene concentration was 36 ug/L in the water phase with pure toxaphene remaining as a separate phase on the pond bottom. Water was pumped directly from the pond to the mixed-media filters and through the activated carbon columns at a rate of 70,000 gallons per day, which resulted in an EBCT of 26 minutes. A total of 251,000 gallons were treated and the toxaphene concentration was reduced from 36 to 1 ug/L.

Mixed Pesticide Incident - Strongstown, Pennsylvania - A pesticide blend of "Termide" and water (2.5 gallons of "Termide," 240 gallons of water) was applied to a local home and contaminated a nearby trout stream causing a significant fish kill. The water had a combined chlordane, heptachlor,

Orange County Water District

Water Factory 21 is an advanced wastewater treatment plant operated by the Orange County Water District (OCWD) in California. The plant effluent is injected into the OCWD aquifer to prevent saltwater intrusion. The treatment processes include lime treatment, air stripping, recarbonation, decarbonation, chlorination, filtration, granular activated carbon adsorption (GAC), reverse osmosis, and final chlorination. Lime treatment and recarbonation are located prior to the carbon adsorption columns in the process train. The 17 carbon adsorption columns in service at Water Factory 21 are each have a diameter of 12 ft and a height of 24 ft and contain 45 tons of 300-mesh carbon. The EBCT of each column is 34 minutes. The columns are operated in parallel and were operated in an upflow mode until late 1977. They were switched to the downflow mode in late 1977 to decrease the carryover of carbon fines. This was done to protect the reverse osmosis membranes from fouling.

McCarty and Reinhard (1980) discussed the effectiveness of the GAC for organic removal during a two-year testing period. The trickling filter effluent from the regional wastewater treatment plant was the influent to Water Factory 21 from October 1976 to February 1978. The wastewater treatment plant switched processes from trickling filtration to activated sludge treatment in March 1978 and its effluent became the feedwater for Water Factory 21. This change resulted in significant differences in the organic characteristics of the influent waters to Water Factory 21. GAC performance for each period is presented in Table 4-3. A significant decrease in the carbon usage rate was observed in the second period due to lower organic loading on the carbon.

Mount Clemens, Michigan

The water treatment plant in Mount Clemens has utilized GAC to remove synthetic organic chemicals from their raw water source at Lake St. Clair for 10 years. Hansen (1977) reported that the eight filters had been changed three times (in 1968, 1970, and 1974). Each filter contains 18 inches of GAC on top of 12 inches of sand. The GAC originally was installed to minimize taste and odor problems. Analysis has shown that pesticides were also removed by the GAC. The pesticides enter the lake during periods of runoff throughout the growing season. During April 1976, water samples contained heptachlor

TABLE 4-3

REMOVAL BY GAC AT THE WATER FACTORY 21

	October 1976 - February 1978				March 1978 - January 1979			
Contaminant	Influent Concentration[1]	Effluent Concentration	Percentage Removal	Carbon Usage Rate (lb/1,000 gal.	Influent Concentration[1]	Effluent Conc.	Percentage Removal	Carbon Usage Rate (lb/1,000 gal)
COD	42	16.8	60	2.4	24	12.24	49	1.2
TOC	14	6.9	51	2.4	NR	NR	-	-
o-dichlorobenzene	0.01	0.002	82	2.4	0.02	0.002	91	1.2
chlorobenzene-o-xylene	0.09	0.049	46	2.4	0.11	0.041	63	1.2
m-xylene	ND	ND	-	2.4	0.05	0.025	50	1.2
ethylbenzene	0.06	0.033	45	2.4	0.02	0.017	17	1.2
styrene	ND	ND	-	-	0.03	0.018	40	1.2

Note:

1. Geometric mean concentration in ug/L, except COD and TOC which are in mg/L.
2. NR - not reported.
3. ND - not detected.

TABLE 4-4

TREATMENT OF SOCS BY GRANULAR ACTIVATED CARBON/FILTRATION

FREMONT, OHIO MAY-OCTOBER, 1984

SOC	Concentration (ug/L)	Percent Removal	Confidence Level	Occurence Days
alachlor	3.70	72 ± 15	99	13
atrazine	4.83	47 ± 17	99.9	17
DEA	0.43	69 ± 31	99	9
DIA	0.27	82 ± 15	93	4
simazine	0.39	62 ± 27	99	11

DEA = diethyl atrazine (metabolite)
DIA = diisopropyl atrazine (metabolite)

The GAC column size and carbon content and operating conditions were not reported. The influent DBCP and EDB concentrations ranged from 77 to 184 ug/L and 8 to 19 ug/L, respectively. The chemical concentrations in the water were reduced below 1 ug/L for EDB and below detectable limits (0.1 ug/L) for the 17 other contaminants. The usage rate during this period averaged 0.31 lb carbon/1,000 gal.

Greenport, New York

Available performance data of existing GAC contactor from start-up (August 1980) through November 1986 was evaluated (Divarka and Bartilucci and Malcolm Pirnie, Inc., July 1987). The GAC contactor operated under the following conditions:

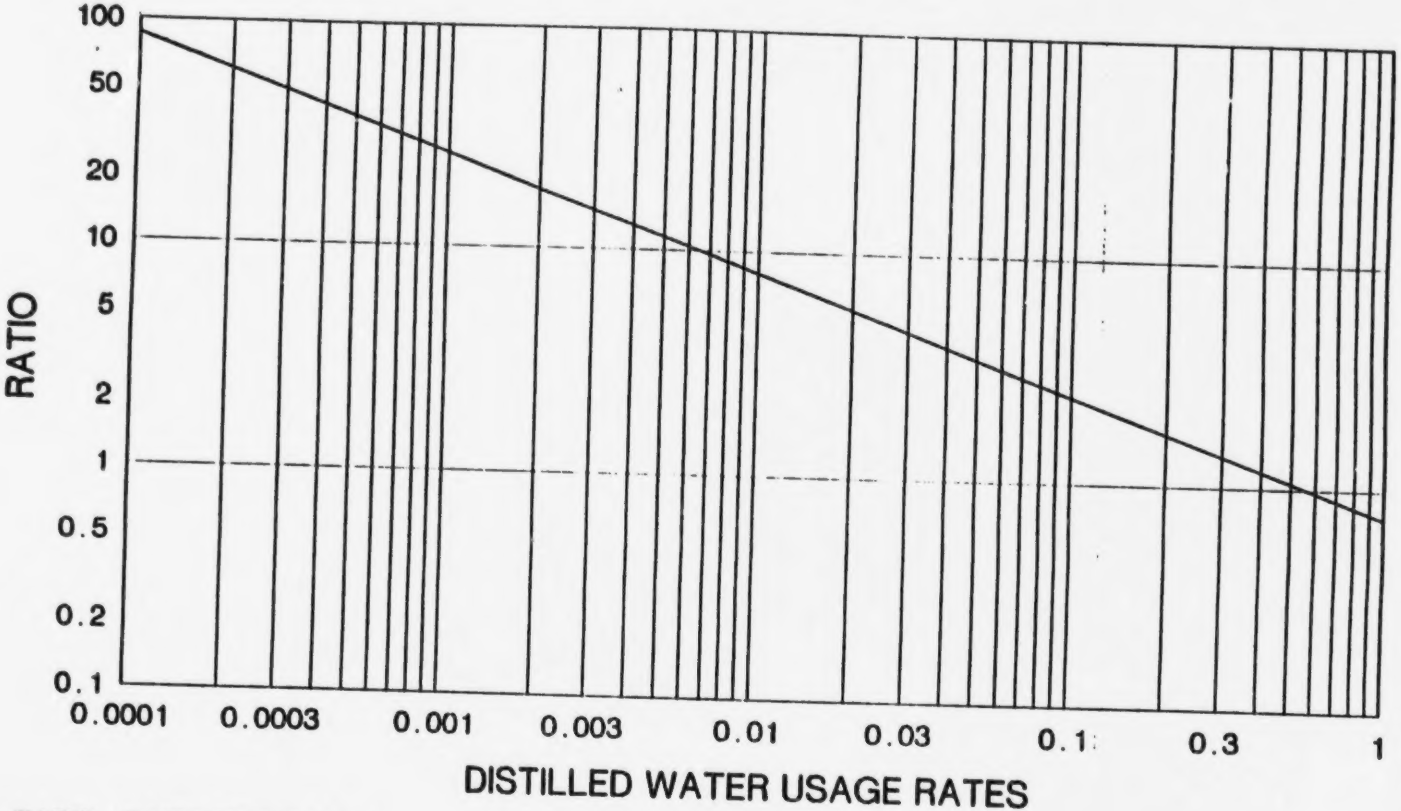
Flow (gpm) 450
Carbon charge (lbs) 20,000
EBCT (minutes) 12

Based on an aldicarb breakthrough criteria of 6 ug/L, carbon usage ranged from 0.15 to 0.17 lbs/1,000 gallons through three carbon changes in the period from August 1980 through July 1984. Since aldicarb levels in the well were decreasing over time, the GAC was changed only once (October 1985) in the period between July 1984 and November 1986.

Estimation of Carbon Usage Rates

The presence of other adsorbable organic compounds and natural and/or anthropogenic organic matter in the water matrix impacts the adsorption of specific organic compound of interest. In a given water matrix, organic compounds compete for the available active sites on the carbon. This results in reduced capacities for all the compounds when compared to their single solute capacities. Competitive interactions impact weakly adsorbing compound more than the strongly adsorbing compound. Further, competitive interactions among organic compounds in a water matrix depends on number of compounds and their concentrations.

FIGURE 4-3



NOTE: RATIO = RATIO OF FIELD TO
DISTILLED WATER USAGE RATES

RATIO OF FIELD:DISTILLED
VERSUS
DISTILLED WATER USAGE RATES

equal to the multiplier times the distilled water carbon usage rate. These adjusted carbon usage rates are presented in Table 4-5 and will be used to develop GAC costs in Section 7.

Summary

The various studies reviewed in this section indicate that all 29 SOCs (with the exception of epichlorohydrin) to be regulated under Phase II can be removed by GAC. The economy of the process is dependent on the carbon usage rate. Certain volatile organics and chlorinated aromatics have relatively poor adsorbabilities, which result in higher carbon usage rates. Because of their volatile nature, these SOCs may be removed more economically by packed column aeration, as discussed in Sections 5 and 7.

Adsorption isotherm tests aid in defining the relative adsorbability of each SOC present in the water. These data should be used along with model predictions to predict minicolumn sizing. Since minicolumn scale-up is currently uncertain, pilot or full scale data should be obtained. Since carbon usage rates are dependent on the organic matrix, natural waters rather than distilled water should be used whenever possible. Carbon usage rates are also dependent upon the following parameters:

- hydraulic conditions
- biological action
- contactor configuration
- operating conditions
- level of pretreatment

Since carbon usage rates are dependent on several variables, further research should be conducted to better define the usefulness of data obtained from all phases of treatability studies.

TABLE 4-5

CARBON USAGE RATES WITH BACKROUND TOC^{1,2,3}

Compound Name		Carbon Usage (lbs/KGal)								
Alachlor	Inf (ug/L)		10.00			50.00			100.00	
	Eff (ug/L)	0.60	2.00	6.00	0.60	2.00	6.00	0.60	2.00	6.00
	Usage Rate	0.0208	0.0206	0.0202	0.0374	0.0371	0.0368	0.0481	0.0477	0.0474
Aldicarb	Inf (ug/L)		50.00			100.00			500.00	
	Eff (ug/L)	1.30	10.00	20.00	1.30	10.00	20.00	1.30	10.00	20.00
	Usage Rate	0.0852	0.0837	0.0826	0.1044	0.1032	0.1023	0.1676	0.1667	0.1656
Atrazine	Inf (ug/L)		5.00			50.00			100.00	
	Eff (ug/L)	1.00	3.00	5.00	1.00	3.00	5.00	1.00	3.00	5.00
	Usage Rate	0.0263	0.0257	---	0.0546	0.0543	0.0541	0.0679	0.0676	0.0674
Carbofuran	Inf (ug/L)		20.00			50.00			100.00	
	Eff (ug/L)	5.00	40.00	50.00	5.00	40.00	50.00	5.00	40.00	50.00
	Usage Rate	0.0459	---	---	0.0604	0.0570	---	0.0741	0.0719	0.0715
Chlordane	Inf (ug/L)		5.00			10.00			50.00	
	Eff (ug/L)	0.50	2.00	5.00	0.50	2.00	5.00	0.50	2.00	5.00
	Usage Rate	0.0306	0.0299	---	0.0386	0.0379	0.0372	0.0660	0.0652	0.0645
cis-1,2-Dichloroethylene	Inf (ug/L)		50.00			100.00			200.00	
	Eff (ug/L)	5.00	70.00	100.00	5.00	70.00	100.00	5.00	70.00	100.00
	Usage Rate	0.3603	---	---	0.4159	0.3966	---	0.4791	0.4656	0.4608
DBCP	Inf (ug/L)		2.00			5.00			20.00	
	Eff (ug/L)	0.10	0.20	1.00	0.10	0.20	1.00	0.10	0.20	1.00
	Usage Rate	0.0358	0.0356	0.0347	0.0449	0.0448	0.0446	0.0627	0.0626	0.0618
o-Dichlorobenzene	Inf (ug/L)		100.00			700.00			1000.00	
	Eff (ug/L)	50.00	600.00	800.00	50.00	600.00	800.00	50.00	600.00	800.00
	Usage Rate	0.0706	---	---	0.1293	0.1234	---	0.1443	0.1401	0.1381
1,2-Dichloropropane	Inf (ug/L)		10.00			50.00			100.00	
	Eff (ug/L)	2.00	5.00	10.00	2.00	5.00	10.00	2.00	5.00	10.00
	Usage Rate	0.2060	0.2013	---	0.2897	0.2867	0.2837	0.3335	0.3312	0.3283
2,4-D	Inf (ug/L)		50.00			100.00			500.00	
	Eff (ug/L)	5.00	70.00	100.00	5.00	70.00	100.00	5.00	70.00	100.00
	Usage Rate	0.0983	---	---	0.1263	0.1224	---	0.2251	0.2212	0.2204

TABLE 4-5 (Continued)

Compound Name		Carbon Usage (lbs/KGal)								
Ethyl benzene	Inf (ug/L)		100.00			700.00			1000.00	
	Eff (ug/L)	50.00	700.00	800.00	50.00	700.00	800.00	50.00	700.00	800.00
	Usage Rate	0.1017	---	---	0.1637	---	---	0.1782	0.1687	0.1660
EDB	Inf (ug/L)		0.50			10.00			50.00	
	Eff (ug/L)	0.01	0.05	1.00	0.01	0.05	1.00	0.01	0.05	1.00
	Usage Rate	0.0663	0.0656	---	0.1455	0.1453	0.1435	0.2222	0.2221	0.2206
Heptachlor[4]	Inf (ug/L)		0.10			1.00			10.00	
	Eff (ug/L)	0.03	0.40	1.00	0.03	0.40	1.00	0.03	0.40	1.00
	Usage Rate	0.0509	---	---	0.0556	0.0556	---	0.0608	0.0608	0.0608
Heptachlor epoxide	Inf (ug/L)		0.10			1.00			10.00	
	Eff (ug/L)	0.03	0.20	1.00	0.03	0.20	1.00	0.03	0.20	1.00
	Usage Rate	0.0201	---	---	0.0283	0.0271	---	0.0379	0.0377	0.0366
Lindane	Inf (ug/L)		0.50			1.00			10.00	
	Eff (ug/L)	0.02	0.20	1.00	0.02	0.20	1.00	0.02	0.20	1.00
	Usage Rate	0.0171	0.0165	---	0.0208	0.0203	---	0.0393	0.0392	0.0387
Methoxychlor	Inf (ug/L)		260.00			400.00			1000.00	
	Eff (ug/L)	100.00	400.00	500.00	100.00	400.00	500.00	100.00	400.00	500.00
	Usage Rate	0.1411	---	---	0.1626	---	---	0.2185	0.2137	0.2123
Monochlorobenzene	Inf (ug/L)		100.00			600.00			1000.00	
	Eff (ug/L)	60.00	100.00	400.00	60.00	100.00	400.00	60.00	100.00	400.00
	Usage Rate	0.1081	---	---	0.1937	0.1930	0.1891	0.2281	0.2274	0.2245
PCB (Aroclor 1254)[4]	Inf (ug/L)		5.00			10.00			50.00	
	Eff (ug/L)	0.05	0.50	5.00	0.05	0.50	5.00	0.05	0.50	5.00
	Usage Rate	0.0224	0.0224	---	0.0222	0.0222	0.0222	0.0217	0.0217	0.0217
Pentachlorophenol	Inf (ug/L)		50.00			500.00			1000.00	
	Eff (ug/L)	20.00	200.00	400.00	20.00	200.00	400.00	20.00	200.00	400.00
	Usage Rate	0.0423	---	---	0.0905	0.0883	0.0860	0.1136	0.1112	0.1101
2,4,5-TP (Silvex)	Inf (ug/L)		50.00			100.00			500.00	
	Eff (ug/L)	5.00	50.00	100.00	5.00	50.00	100.00	5.00	50.00	100.00
	Usage Rate	0.0678	---	---	0.0841	0.0813	0.0000	0.1373	0.1353	0.1341

TABLE 4-5 (Continued)

Compound Name	Carbon Usage (lbs/KGal)									
Styrene	Inf (ug/L)		10.00			50.00			200.00	
	Eff (ug/L)	2.00	5.00	20.00	2.00	5.00	20.00	2.00	5.00	20.00
	Usage Rate	0.0401	0.0395	---	0.0610	0.0605	0.0596	0.0872	0.0866	0.0858
Tetrachloroethylene	Inf (ug/L)		50.00			100.00			500.00	
	Eff (ug/L)	1.00	5.00	50.00	1.00	5.00	50.00	1.00	5.00	50.00
	Usage Rate	0.0980	0.0967	---	0.1160	0.1144	0.1108	0.1699	0.1694	0.1657
Toluene	Inf (ug/L)		500.00			3000.00			5000.00	
	Eff (ug/L)	100.00	2000.00	3000.00	100.00	2000.00	3000.00	100.00	2000.00	3000.00
	Usage Rate	0.1936	---	---	0.3160	0.3050	---	0.3626	0.3540	0.3508
Toxaphene	Inf (ug/L)		5.00			10.00			50.00	
	Eff (ug/L)	1.00	5.00	10.00	1.00	5.00	10.00	1.00	5.00	10.00
	Usage Rate	0.0434	---	---	0.0493	0.0432	---	0.0634	0.0604	0.0579
trans-1,2-Dichloroethylene	Inf (ug/L)		50.00			200.00			500.00	
	Eff (ug/L)	5.00	100.00	200.00	5.00	100.00	200.00	5.00	100.00	200.00
	Usage Rate	0.2670	---	---	0.3888	0.3793	---	0.4977	0.4893	0.4859
m-Xylene	Inf (ug/L)		10000.00			20000.00			50000.00	
	Eff (ug/L)	1000.00	10000.00	15000.00	1000.00	10000.00	15000.00	1000.00	10000.00	15000.00
	Usage Rate	0.2116	---	---	0.2340	0.2148	0.2065	0.2649	0.2515	0.2468
o-Xylene	Inf (ug/L)		10000.00			20000.00			50000.00	
	Eff (ug/L)	1000.00	10000.00	15000.00	1000.00	10000.00	15000.00	1000.00	10000.00	15000.00
	Usage Rate	0.3096	---	---	0.3718	0.3619	0.3556	0.4733	0.4644	0.4620
p-Xylene	Inf (ug/L)		10000.00			20000.00			50000.00	
	Eff (ug/L)	1000.00	10000.00	15000.00	1000.00	10000.00	15000.00	1000.00	10000.00	15000.00
	Usage Rate	0.3151	---	---	0.3822	0.3718	0.3657	0.4966	0.4882	0.4854

Notes:

1. Carbon usage rates developed from predictions presented in Table 4-2 and application of safety factors to account for background TOC and possible competition from other SOCs

2. Model-predicted carbon usage rates developed through application of CPHSDM to distilled-water isotherm study results and were adopted from:
   (a) Miltner, R.J. et al. Final Internal Report On Carbon Use Rate Data. ODW - U.S. EPA, Cincinnati, OH, June 30, 1987.
   (b) Miltner, R.J. et al. Interim Internal Report On Carbon Use Rate Data. ODW - U.S. EPA, Cincinnati, OH, June 30, 1987.

3. Distilled-water isotherm constants not available for Acrylamide, Aldicarb sulfone, Aldicarb sulfoxide, and Epichlorohydrin

4. Isotherm-predicted carbon usage rates developed through application of Freundlich's equation, as shown in Appendix A.

5. OTHER APPLICABLE TECHNOLOGY - PACKED COLUMN AERATION

As indicated in Section 3, packed column aeration has been identified as another applicable technology. Other applicable technologies are those technologies which are not identified as generally utilized for removal of SOCs, but which may have applicability for some water supply systems when considering site-specific conditions, such as type of SOC.

Process Description

Air stripping has been used effectively in water treatment to reduce the concentration of taste and odor producing compounds and certain organic compounds. Aeration, or air stripping, may be described as the transfer of a substance from solution in a liquid to solution in a gas. The driving force for mass transfer is a concentration gradient. A concentration gradient tends to move the substance in such a direction as to equalize concentrations and, thereby, eliminate the gradient.

The driving force for mass transfer is the difference between actual conditions in the air stripping unit and conditions associated with equilibrium between the gas and liquid phases. According to Henry's Law the equilibrium concentration of a solute in air is directly proportional to the concentration of the solute in water at a given temperature. Henry's Law states that the amount of gas that dissolves in a given quantity of liquid, at constant temperature and total pressure, is directly proportional to the partial pressure of the gas above the solution. Thus, the Henry's Law Coefficients describe the relative tendency for a compound to separate between gas and liquid. Henry's Law Coefficients can be used to give a preliminary indication of the effectiveness for removing a specific SOC.

Henry's Law Coefficients, are presented for several of the SOCs in Table 5-1 based on both theoretical calculations and field data. The magnitudes of the coefficients for the various compounds are functions of their solubility in the liquid phase and their volatility. A high Henry's Law Coefficient indicates equilibrium favoring the gaseous phase; i.e., the compound generally is more easily stripped from water than one with a lower

TABLE 5-1

HENRY'S LAW COEFFICIENTS FOR SOCs[1]

Compound	MW (g/mole)	Vapor Pressure (mmHg)	Vapor Pressure (Tref)	Solubility (mg/L)	Solubility (Tref)	Henry's Coefficient (atm) (Vp/Sol)(1)	Henry's Coefficient (atm) Field Data(2)
Toxaphene	412	0.2-0.4	20C	3	25C	1004-2008 ✓	136(3)
Trans-1,2-Dichloroethylene	96.95	200	14C	600	20C	1180	150(3)
Cis-1,2-Dichloroethylene	96.95	200	25C	800	20C	886	83
Tetrachloroethylene	165.83	14	20C	150	25C	566 ✓	274
Ethyl Benzene	106.16	7	20C	152	25C	179 ✓	174
Toluene	92.13	22	20C	515	20C	144	162
p-Xylene	106.16	6.5	20C	198	25C	127	150
m-Xylene	106.16	6	20C	NA		NA	137
o-Xylene	106.16	5	20C	175	20C	111 ✓	125
Heptachlor	373.53	0.0003	25C	0.056	25C	73 ✓	42(3)
Monochlorobenzene	112.56	8.8	25C	500	20C	72	75
1,2-Dichloropropane	112.99	42	20C	2700	20C	64	50
Styrene	104.14	5	20C	300	20C	63	-
o-Dichlorobenzene	147.01	1	20C	100	20C	54	39
PCB (Arochlor 1242)	258	0.001	20C	0.24	NA	39 ✓	-
Ethylene dibromide (EDB)	187.88	11	20C	4310	30C	18	17
PCB Aroclor 1254	326	0.00006	20C	0.056	NA	13	-
Heptachlor Epoxide	389.83	0.003	25C	0.35	25C	12	1.8(3)
Dibromochloropropane	236.36	0.8	21C	1000	25C	7	-
Chlordane	409.8	0.00001	20C	0.056	NA	3	2.7(3)
Epichlorohydrin	92.53	12	20C	60000	20C	1	-
Pentachlorophenol	266.35	0.00011	20C	14	20C	7.65E-02	-
Lindane	290.85	9.40E-06	20C	17	24C	5.88E-03	-
Acrylamide	71.08	2	87C	2.15E-06	30C	2.42E-03	-
Alachlor	269.77	2.20E-05	25C	140	23C	1.55E-03	-
Carbofuran	221.3	0.00002	23C	700	25C	2.31E-04	-
Aldicarb	190.25	1.00E-04	25C	6000	25C	1.16E-04	-
Atrazine	215.68	3.00E-07	20C	70	25C	3.38E-05	-
2,4-D	221.04	NA		540	20C	NA	-
2,4,5-TP	269.53	NA		140	25C	NA	-
Methoxychlor	365.65	NA		0.04	24C	NA	-

Notes:

1. Henry's Law coefficient estimated from vapor pressure and solubility data. A 50 percent factor of safety was applied to all estimates.
2. Henry's coefficient based on field evaluation. The indicated value gave the best fit between predicted and observed performances (Cummins and Westrick, 1987).
3. Henry's coefficient based on experimental data (Warner, Cohen and Ireland, 1980).
4. "___" Information not available.

contact of the liquid with the gas and minimizes the thickness of the water layer on the packing, thus promoting efficient mass transfer.

The design of air stripping equipment has been developed extensively in the chemical engineering industry for handling concentrated organic solutions. The procedures used in the chemical engineering literature can be applied to water treatment for trace organics removal. The rate at which a volatile compound is removed from water by aeration depends on the following factors:

- Air:water ratio
- Packing height
- Available area for mass transfer
- Temperature of the water and the air
- Physical chemistry of the contaminant

The first three factors may be controlled in the design of an air stripping unit, while the other two factors are set for a specific water supply.

The air flow requirements for a packed column depend on the Henry's Law Coefficient for the particular compound(s) to be removed from the water. In an ideal aeration system, the minimum air:water ratio which will achieve complete removal of a contaminant proportional to the reciprocal of the Henry's Law Coefficient. The greater the Henry's Law Coefficient, the less air is required to remove the compound from water. Because aeration systems are not ideal, the actual air:water ratios required to achieve a given removal efficiency are greater than the theoretical minimum air:water ratios.

The packing height is a function of the depth of the packing material. An increase in the depth of packing material results in a greater contact time between the air and the water, and consequently, will result in higher SOC removals.

The available area for mass transfer is a function of the packing material. Various sizes and types of packing material are available including 1/4 to 3-inch sizes of metal, ceramic or plastic material. In general, smaller packing material provides a greater available area for mass transfer per volume of material, thus increasing the mass of contaminant removed. However, smaller packing increases the air pressure drop through the packed column.

The fundamental concept of mass transfer states that the rate of mass transfer per unit of reactor volume is first order and proportional to the

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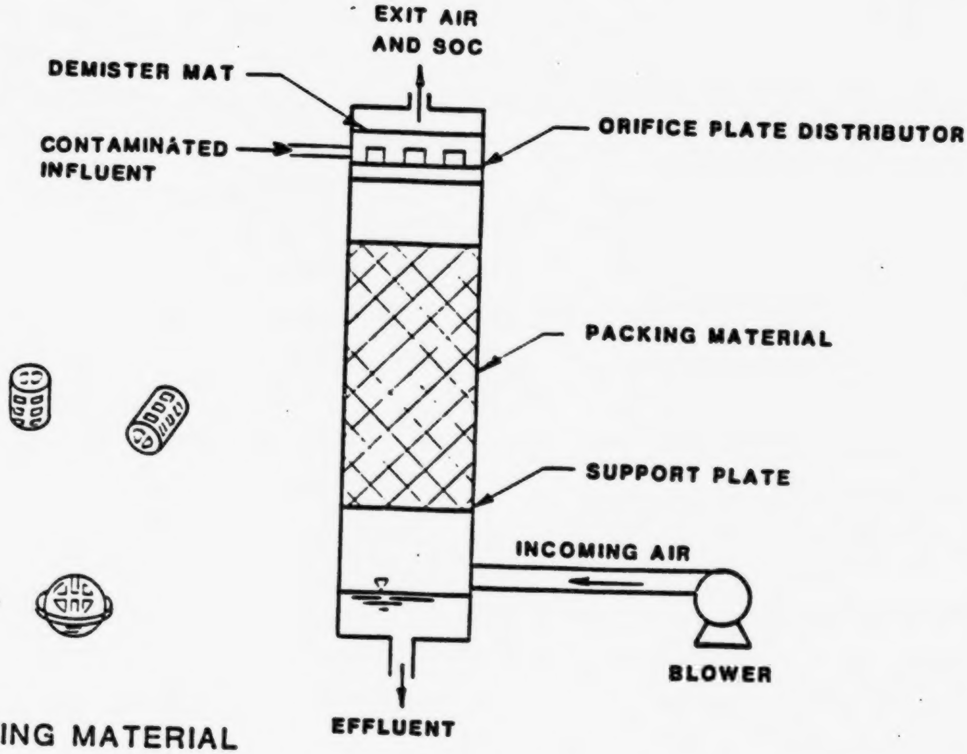
FIGURE 5-1


EXIT AIR AND SOC
DEMISTER MAT
CONTAMINATED INFLUENT
ORIFICE PLATE DISTRIBUTOR
PACKING MATERIAL
SUPPORT PLATE
INCOMING AIR
BLOWER
EFFLUENT

PACKING MATERIAL

PACKED COLUMN

SCHEMATIC OF PACKED COLUMN AERATION

- **Packed Tower:** Metal (steel or aluminum), plastic, fiberglass or concrete is used for the outer shell. Internals (packing, supports, distributors, mist eliminators) are generally made of metal or plastic.
- **Blower:** Typically centrifugal type, either metal or plastic construction. Noise control may be required depending on the size and system location.
- **Effluent Storage:** Generally provided as a concrete clearwell below the packed tower.
- **Effluent Pumping:** Generally required because effluent is usually at atmospheric pressure. Vertical turbine pumps mounted on clearwell are typical.

In ground water applications, water is generally pumped directly from wells to the top of the packed tower. The effluent flows from the bottom of the tower into a clearwell from where it is usually pumped into the distribution system. Depending upon the hydraulic constraints of an individual location, this effluent repumping may or may not be required. Similarly, in surface water applications, the system hydraulics dictate the amount of pumping that is required.

Treatability Studies: Pilot Scale Tests

The feasibility of removing SOCs from drinking water using packed column aeration has been studied in several pilot-scale tests. Seven of the twelve studies reported in this section were conducted by the United States Environmental Protection Agency (USEPA) through its Office of Drinking Water (ODW). The remaining five studies were conducted by other consulting firms or individuals.

Packed-Column Aeration Studies-USEPA

Numerous packed-column aeration pilot studies have been performed by Cummins of USEPA. Seven of the available studies contain removal information on at least one of the 29 SOCs. Data on the removal of cis-1,2-dichloroethylene are presented in each of these studies. The study locations, testing dates and compounds removed (on the list of 29 SOCs) are as follows:

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Liquid Loading Rate (gpm/ft^2)	Air: Water Ratio	Percent Removals cis-1,2-dichloro-ethylene (1)	 1,2-dichloro-propane (2)	 o-dichloro-benzene (3)
12	80	99.7*	98.8*	97.5*
16	47	98.7*	97.7*	91.0*
25	27	91.8	75*	57
35	16	75	54	31
51	8	53	34	6.7
56	5	32	20	-

Notes:

1. Average influent concentration: 11 ug/L
2. Average influent concentration: 2.0 ug/L
3. Average influent concentration: 3.0 ug/L

*Compound stripped below detectable limit - removal efficiency based on regression analysis.

The results indicate that packed column aeration is effective for the removal of each of the three SOCs. Removals decreased as the air:water ratio was lowered, as predicted by the empirical development.

Lansdale, Pennsylvania - The ground water from Well No. 8 on Third Street in Lansdale, Pennsylvania was found to be contaminated by a number of organic chemicals, including cis-1,2-dichloroethylene at a concentration of approximately 160 ug/L. The 100 gpm well was taken out of service in 1979. A total of six runs were conducted by Cummins at the Lansdale site (Cummins, Lansdale, 1982). The water temperature was approximately 58 F. Test conditions and performance data are presented below for cis-1,2-dichloroethylene:

Liquid Loading Rate (gpm/ft^2)	Air: Water Ratio	Percent Removal cis-1,2-dichloroethylene
11	83	99.6
16	44	98.2
24	28	91.8
33	17	82
47	9	50
65	5	30

As in the study at Dedham, the above results indicate that packed-column aeration is effective for the removal of cis-1,2-dichloroethylene.

TABLE 5-2

PACKED-COLUMN PILOT STUDY RESULTS - GLEN COVE, NEW YORK

Liquid Loading Rate (gpm/ft^2)	Air: Water Ratio	Percent Removal cis-1,2-dichloroethylene
Day 1: August 20, 1982; 1-inch Plastic Saddles; Water Temperature = 61 F		
10.3	86	99.9
16.2	46	99.3
25.0	27	94.2
33.9	17	85
51.5	9	58
66.3	6	40
Day 2: December 14, 1982; 1-inch Plastic Saddles; Water Temperature = 58 F		
16.2	47	98.8
25.0	26	94.3
35.3	15	70
50.1	8	46
Day 3: December 16, 1982; 2-inch Plastic Saddles; Water Temperature = 59 F		
11.8	84	98.8
19.1	48	95.8
26.5	28	90
39.8	16	76
57.4	9	54
76.6	5	39

Liquid Loading Rate (gpm/ft^2)	Air: Water Ratio	Percent Removal cis-1,2-dichloroethylene
10	85	99.5
17	45	97.4
25	25	86
35	15	74
50	9	35
52	5	24

Once again, the results strongly indicate that packed-column aeration is an effective means for the removal of cis-1,2-dichloroethylene.

Bastrop, Louisiana - The City of Bastrop, LA was selected for field evaluation due to a gasoline spill which occurred a short distance from a municipal well field. As a result of the contamination, the Liberty Street well #2 was taken out of service. The principal contaminants in the well water were:

SOC	Average Concentration (ug/L)
Benzene	190
Toluene	62
Ethylbenzene	9
o-Xylene	10
m-Xylene	2.9
p-Xylene	6.9

The well had a pumping capacity of 1050 gallons per minute (gpm) at the distribution system pressure and 1500 gpm at atmospheric pressure. The water temperature was 20°C. The results of the pilot testing are summarized below (Cummins, 1984):

Liquid Loading Rate (gpm/Ft^2)	Air Water Ratio	Percent Removal					
		Benzene	Toluene	Ethyl-benzene	o-xylene	m-Xylene	p-Xylene
9.1	87	>99.6	>98.8	>92	>95	>83	>90
30.9	25	98.2	98.3	>92	>95	>83	>90
66.3	8.5	85.4	81.5	85.8	74.3	77.5	83

These results indicate that of packed column aeration effectively removes these SOCs from drinking water.

TABLE 5-3

PACKED-COLUMN AERATION PILOT STUDY RESULTS - ARIZONA

Run No.	Liquid Loading Rate (gpm/ft^2)	Air: Water Ratio	Ethylbenzene Concentration (ug/L) Influent	Ethylbenzene Concentration (ug/L) Effluent	Percent Removal	Toluene Concentration (ug/L) Influent	Toluene Concentration (ug/L) Effluent	Percent Removal	m-Xylene Concentration (ug/L) Influent	m-Xylene Concentration (ug/L) Effluent	Percent Removal	o-, p-Xylene Concentration (ug/L) Influent	o-, p-Xylene Concentration (ug/L) Effluent	Percent Removal
1	15.3	80:1	73.9	5.2	93.0	13400	111	99.2	1040	70.9	93.2	1450	93.3	93.6
2	44.6	10:1	200	56.5	71.8	4270	1130	73.5	1900	486	74.4	1980	633	68.0
3	20.4	59:1	202	3.9	98.1	4520	114	97.5	1900	79.4	95.8	1980	116	94.1
4	25.5	46:1	91	6.2	93.2	4350	168	96.1	1750	121	93.1	1980	179	91.0
5	35.7	25:1	<0.1	<0.1	--	2880	488	83.1	945	182	80.7	1170	270	76.9
6	17.8	71:1	<0.1	<0.1	--	3050	20.9	99.3	1020	18.2	98.2	1210	62.9	94.8
7	50.9	30:1	<0.1	<0.1	--	3190	142	95.5	1050	65.5	93.8	1260	162	87.1
8	12.7	126:1	44.8	<0.1	>99.8	3420	11.6	99.7	1090	7.3	99.3	1300	18.0	98.6
9	25.5	63:1	59.7	<0.1	>99.8	3720	88.4	97.6	1160	50.9	95.6	1350	89.9	93.3

results are presented in Table 5-4. Higher removals of DBCP were achieved at higher air to water ratios and higher temperatures. At low temperatures higher air to water ratios were required to achieve removals similar to those obtained at higher temperatures. This illustrates the effect of temperature on air stripping as predicted by the empirical development earlier in this section.

Selleck also reported the results for EDB removal. The water temperature was approximately 64°F during the two runs that were performed.

Liquid Loading Rate (gpm/ft^2)	Air: Water Ratio	EDB Concentration Influent ug/L	Percent Removal
2.4	200	16.0	>94*
9.7	210	9.1	>90*

*Effluent EDB Concentration below estimated detention limit of approximately 0.9 ug/L.

The results indicate that packed-column aeration effectively removes EDB from drinking water.

Arizona - A pilot-study was conducted by Malcolm Pirnie, Inc. (1987) to evaluate the feasibility of removing DBCP from well water at a site in Arizona. The PVC column was 24 inches in diameter with a maximum packing height of 10 feet. Results of the test are summarized in Table 5-5. In general, the test results indicated that high air:water ratios (200:1 or higher) were required for effective DBCP removal. The performance of two types of packing materials were also compared, leading to an optimized design of the full-scale facility.

Gainsville, Florida - ESE (1983) conducted pilot air stripping tests for EDB removal. Feed water spiked with various concentrations of EDB was used in the study. The pilot system consisted of four, 1.5-foot diameter columns operated in series, which allowed for up to 50 feet of total packed column height. The cumulative height breakdown was as follows:

Column 1 = 15 feet
Column 2 = 30 feet
Column 3 = 40 feet
Column 4 = 50 feet

TABLE 5-4

PACKED COLUMN PILOT STUDY RESULTS -BERKELEY

Liquid Loading: 2.4 gpm/Ft^2 TEMP(°F)	Air:Water Ratio	DBCP Influent Concentration (ug/L)	Percent Removal
69.3	180	52.5	75.5
69.3	200	6.8	88.6
68.4	180	18.8	74.2
67.8	590	414	94.0
67.3	210	544	71.3
67.3	200	131	76.2
66.1	550	54.0	92.4
57.0	680	665	88.7
56.5	670	29.6	89.6
55.9	480	673	86.6
55.9	450	28.3	79.8
55.8	560	34.4	86.1
51.6	490	329	83.5
51.4	650	320	86.9
51.3	590	327	86.6
50.4	650	15.9	87.6
50.2	560	15.2	83.2
50.2	490	15.9	73.5
Liquid Loading: 4.8 gpm/Ft^2			
68.2	250	76.1	79.8
67.8	570	14.5	97.5
67.3	580	369	97.1
67.1	410	534	88.8
66.7	490	50.5	94.3
66.6	570	25.0	98.0
66.2	270	13.8	83.4
65.7	270	494	79.6
64.9	510	11.5	96.8

Liquid Loading: 7.25 gpm/Ft^2 TEMP(°F)	Air:Water Ratio	DBCP Influent Concentration (ug/L)	Percent Removal
58.1	320	101	91.6
57.2	340	771	81.3
55.0	330	9.84	91.1
Liquid Loading: 9.7 gpm/Ft^2			
64.4	220	772	77.4
63.9	220	85.3	79.7
63.1	220	12.2	87.6

TABLE 5-5

PACKED COLUMN PILOT STUDY RESULTS - ARIZONA(1)

Liquid Loading Rate (gpm/sf)	Air Water Ratio (cf:cf)	DBCP Concentration (ug/L)		Percent Removal
		Influent	Effluent	
No. 1 Jaeger Tri-Packs:				
6.2	199	0.20	0.10	50.0
6.2	377	0.25	0.09	64.0
9.4	107	0.25	0.16	36.0
9.1	215	0.26	0.13	50.0
10.5	173	0.07	0.05	28.6
8.9	284	0.23	0.11	52.2
12.9	76	0.24	0.18	25.0
12.5	186	0.25	0.14	44.0
16.1	75	0.24	0.17	29.2
15.8	132	0.26	0.18	30.8
22.7	80	0.31	0.19	38.7
No. 2 Glitsch Mini-Rings:				
22.6	83	0.25	0.20	20.0
16.1	129	0.25	0.14	44.0
13.5	154	0.31	0.11	64.5
9.8	239	0.26	0.13	50.0
6.4	428	0.30	0.04	86.7
6.1	276	0.26	0.05	80.8
16.4	89	0.26	0.17	34.6
13.2	74	0.26	0.17	34.6
10.0	81	0.25	0.17	32.0
10.0	165	0.25	0.09	64.0
11.1	149	0.15	0.04	73.3

Note:

1. All results are from the use of 9.5 feet of packing and a water temperature of 75 degrees F.

TABLE 5-6

Packed Column Pilot Study Results -Gainesville

			EDB Concentration (ug/L)				
				Effluent			
Run Number	Liquid Loading (gpm/Ft^2)	Air:Water Ratio	Influent	15 Ft	30 Ft	40 Ft	50 Ft
1	11.3	7.9	195.5	162.5	127.5	103.5	79
2	11.3	15.0	102	61.4	32.0	19.9	12
3	11.3	22.5	107.5	47.7	18.9	9.08	4.6
4	11.2	33.8	88.6	27.7	8.4	3.05	1.2
5	22.6	15	91.3	54.5	34.4	22.8	15.3
6	22.6	22.5	90.7	40.6	19.2	9.52	5.06
7	22.4	35	92.6	24.7	8.6	3.15	1.19
8 (1)	11.2	88.3	88.7	4.54	0.53	0.095	0.02
		66.5					
		64.5					
		65.3					

Note:

1. Run 8 conducted at four different air: water ratios to determine the highest removal efficiency obtainable with the system.

samples were taken and pressure drop was measured until steady state was attained. Test results are presented in Table 5-7. The test results indicate that air stripping effectively removes these SOCs from water. Removals generally increased with increasing air to water ratio.

Oklahoma State University, Oklahoma - Stover (1982) reported on pilot studies for the treatment of contaminated well water by air stripping. The wells were adjacent to an industrial park and contained trans-1,2-dichloroethylene and several other volatile organic contaminants. The column was a 4-inch diameter glass column packed with 25 inches of 6mm glass raschig rings. The study was conducted at various air to water ratios and the results for trans 1,2-dichloroethylene in Well No. 2 are as presented below:

Liquid Loading Rate gpm/ft^2	Air: Water Ratio	Concentration (ug/L)		Percent Removal
		Influent	Effluent	
8.6	9.3	40	11	72.5
0.68	114.0	40	1	97.5
10.1	10.7	16	3	81.3

The results indicate that air stripping is effective in removing trans-1,2-dichloroethylene from water.

Full-Scale:

Full-scale data are available from several installations. These facilities and the associated performance data for SOC removal are described below:

Tacoma, Washington - Nadeau et al. (1983) describe a large packed-tower aeration system in Tacoma, Washington designed to treat the water from one of the city's largest production wells. The well was shut down in 1981 after it was found to be contaminated with trans-1,2-dichloroethylene (30-100 ug/L), trichloroethylene (54-130 ug/L), tetrachloroethylene (2-5 ug/L), and 1,1,2,2-tetrachloroethane (17-300 ug/L). The full-scale system was designed on the basis of pilot-scale testing. It consists of five packed columns, each 12 feet in diameter and containing 21 feet of 1-inch plastic saddle packing. The overall height of each column is 50 feet, including the discharge stack. In addition, each tower is equipped with a 60-hp blower capable of delivering 29,000 cfm through each column.

TABLE 5-7

PACKED COLUMN PILOT STUDY RESULTS - IOWA CITY

Liquid Loading (gpm/ft^2)	Air: Water Ratio (ft^3/ft^3)	Concentration (mg/L)		Percent Removal
		Influent	Effluent	
Trans-1,2-dichloroethylene				
4.21	25	5.4	1.7	69
4.62	50	114	27.9	76
4.62	50	3.2	0.9	72
2.79	100	105	16.6	84
2.79	100	7.3	1.5	80
Toluene				
4.21	25	3.4	0.9	74
4.62	50	39.7	9.1	77
4.62	50	5.3	1.2	77
2.79	100	37.1	2.8	93
1.63	200	2.7	0.1	96
Benzene				
4.21	25	8.4	2.8	67
4.62	50	105	24.2	77
4.62	50	10.5	2.9	72
2.79	100	92.5	9.3	90
2.79	100	11.8	2.9	75
Chlorobenzene				
4.21	25	13.3	4.6	65
4.62	50	22.8	6.4	72
4.62	50	9.2	2.6	72
2.79	100	29.6	3.3	89
2.79	100	7.8	1.8	77
1.63	200	3.6	0.1	97
o-Dichlorobenzene				
4.21	25	14.2	5.7	60
4.62	50	5.3	2.9	45
4.62	50	27.8	8.3	70
2.79	100	24.0	6.2	74
1.63	200	11.0	0.7	94

The two packed column air strippers at Water Factory 21 are both rectangular. Each is 63 m long and 19 m wide and contains 7.6 m of polypropylene splash-bar packing. The total packing volume per tower is therefore approximately 9,000 m^3. The flow treated by each tower is 7.5 mgd at an air:water ratio of 3000:1.

The decarbonators present at Water Factory 21 are much smaller than the stripping towers and were not specifically designed to remove synthetic organic chemicals. Each is 2 m square and contains 2.4 m of polyethylene packing. The total packing volume per decarbonator is therefore approximately 19 m^3. The flow treated by each decarbonator is 2.5 mgd at an air:water ratio of 22:1.

Available removal performance results of the air strippers for five SOCs are presented below:

Compound	Air Stripper Concentrations (ug/L) Influent	 Effluent	Percent Removal
Ethylbenzene	0.23	0.10	56.5
	0.067	0.041	38.8
m-Xylene	0.086	0.070	18.6
Styrene	0.076	0.037	51.3
PCB (Aroclor 1242)	0.37	0.36	2.7
1,2-dichlorobenzene	1.2	0.18	85.0
	0.56	0.066	88.2

The air stripper results indicate that packed column aeration is moderately effective for removal of ethylbenzene and styrene. The removals of m-xylene and PCB (Aroclor 1242) are fairly low. However, the low influent and effluent concentrations must be taken into account when judging the removals. Actual performance data were not available for the decarbonator.

Slat-Tray Aeration Facility - Hess et al. (1981) described a slat-tray aeration unit installed in Norwalk, Connecticut designed to treat the ground water from a wellfield along the Silvermine River. An industrial spill occurred in this river and such organic compounds as trichloroethylene (predominately), tetrachloroethylene, cis-1,2-dichloroethylene, trans-1,2-dichloroethylene, 1,1-dichloroethylene, and 1,1,1-trichloroethane

7

TABLE 5-8

FULL SCALE PACKED COLUMN AERATION DATA

Location	Flow (mgd)	No. of$^{(1)}$ Columns	Liquid Loading (gpm/sq ft)	Column$^{(2)}$ Diameter (ft)	Column Height (ft)	Packing Height (ft)	Packing Size (in)	Packing Type	Air:Water Ratio	Contaminant$^{(3)}$	Influent Conc. (ug/L)	Percent Removal	Clearwell Capacity (gal)
Hatboro, PA	0.31	1	9.0	5.5	34	25	4	Tripacks	220:1	PCE	10	>98	7,500
Hatboro, PA	0.4	1	17.3	4.5	29	24	2	Tripacks	120:1	PCE	10	>95	7,500
Brewster, NY	0.5	1	19.5	4.75	NA	18	1	Saddles	33:1	PCE	110	>99	20,000
										c-1,2-DCE	49	>99	
Mountainside, NJ	0.9	1	31.3	5 x 4	34	26	2	Tripacks	40:1	PCE	100	90	23,000
Baldwin Park, CA	1.4	1	20.0	8.0	33	18	1	Saddles	30:1	PCE	330	>99	None
Garden City Park, NY	1.7	1	27.2	7.5	24	16	NA	Tripacks	35:1	PCE	90	>94	11,200
Northport, NY	1.9	1	46.0	6.0	25.5	16	1,2	Saddles	30:1	PCE	450	99	13,000
Hicksville, NY	2.0	2	17.8	10.0	28	20	NA	Tripacks	30:1	c-1,2-DCE	NA	98	33,600
Waussau, WI	2.9	2	28.2	9.5	29	24.5	3	Saddles	30:1	c-1,2-DCE	82	>96	None
										PCE	60	98	
Great Neck, NY	3.0	1	26.5	10.0	33	24	1	Tripacks	100:1	PCE	55	>99	33,000
New Hyde Park, NY	3.5	1	28.6	12 x 7	25	21	2	Tripacks	40:1	PCE	100	90	24,300
Queens, NY	4.3	1	35.7	12 x 7	19	15	2	Tripacks	40:1	PCE	300	97	24,300

Notes:

1. Parallel operation for sites with more than one column, unless otherwise noted.

2. Or rectangular dimensions.

3. PCE indicates Tetrachloroethylene.
   c-1,2-DCE indicates CIS-1,2-Dichloroethylene.

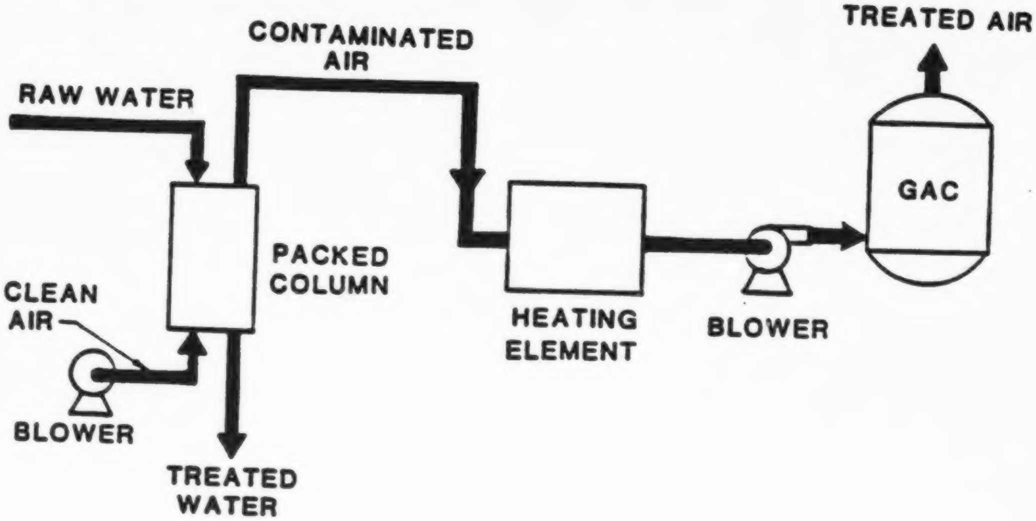
4. NA - Data Not Available.

Pilot-study with vapor-phase GAC adsorption (Crittenden et al, 1987) indicates that carbon adsorption is currently the most effective method for removing low-level organics from the packed column exit air. Vapor-phase adsorption is attractive for two reasons: the vapor-phase mass transfer zone (MTZ) is much shorter than the liquid-phase MTZ and the cross-sectional area requirement of the fixed bed is much smaller. The carbon usage rates for vapor-phase adsorption are also less than those for liquid-phase. A schematic of the vapor-phase GAC system is illustrated on Figure 5-2.

In operating a vapor-phase GAC system, the relative humidity of the off-gas must be reduced to prevent condensation of water vapor in the carbon pores. This can be accomplished by heating the air prior to entering the GAC contactor. The competition of water-vapor adsorption and gas-phase SOC adsorption onto GAC is also minimized at off-gas relative humidity of 40 to 50 percent (Crittenden, 1987). A major concern pertaining to vapor-phase GAC systems is predicting the contaminant breakthrough. At present, reliable methods to estimate the vapor-phase GAC bed life are not available. Possible approaches including monitoring the GAC effluent air quality (either on a continuous basis or a batch mode), using a mass balance around the contactor, or a combination of the two approaches.

A bed from the pilot plant in Wausau containing trichloroethylene (TCE) and tetrachloroethlene (PCE) was regnerated three times and the TCE capacity decreased from 80 to 60 percent of the virgin capacity over the three cycles. The reduction in TCE capacity with successive adsorption/regeneration cycles was due to the buildup of a PCE heel on the GAC, since PCE was not removed well under the conditions used (100 C, 1 atm). The equillbrium model showed that this could be solved by using saturated steam 50 C above the boiling point of PCE (121 C).

FIGURE 5-2


CONTAMINATED AIR
TREATED AIR
RAW WATER
GAC
PACKED COLUMN
CLEAN AIR
HEATING ELEMENT
BLOWER
BLOWER
TREATED WATER

SCHEMATIC OF VAPOR-PHASE GAC SYSTEM

6. ADDITIONAL TECHNOLOGIES

As indicated in Section 3, there are several additional treatment technologies capable of removing SOCs from drinking water. Additional technologies are those which have been shown to have potential for SOC removal but for which either the potential is limited or insufficient data prevents full evaluation of the technology. The following additional technologies have been identified:

Powdered Activated Carbon (PAC)
Diffused Aeration
Oxidation
Reverse Osmosis
Conventional Treatment

Powdered Activated Carbon (PAC)

PAC represents another way of applying adsorption technology, which has been found to be applicable for SOC removal. PAC may achieve removal of certain SOCs and may have limited applicability in locations having certain constraints (e.g. hydraulic, space) or where SOCs enter a surface water on an intermittent (e.g., seasonal) basis. Generally, PAC addition is found to be less efficient than GAC adsorption for SOC removal, as PAC operates at a lower equilibrium capacity than GAC.

Process Description

PAC traditionally has been used in water treatment plants for removing trace organic compounds associated with taste and odor problems. Fewer studies have been conducted on the use of PAC for removing organics frequently found in ground water supplies primarily because preliminary data have indicated that very large dosages of PAC would be necessary to achieve satisfactory removals. Pilot and full-scale studies indicate mixed results on the effectiveness of PAC, although most studies to date agree that PAC has limited applicability.

PAC requires as coagulation/sedimentation facilities: feed equipment, mixing chambers, clarifiers, and filtration. Therefore, unless these facilities are already in place, PAC is not economically suited to the treatment of ground water. GAC is the preferred activated carbon process for ground water systems. In addition, the use of PAC entails additional sludge

TABLE 6-1

CONTROL OF SOCS USING POWDERED ACTIVATED CARBON[1]

SOC[4]	SOC Concentration ug/L	PAC Type	Percent Removal									
			PAC Dose, mg/L									
			5.7	8.6	11.4	16.7	17.1	22.8	25.7	28.5	33.3	34.2
atrazine[5]	125	F400[3]				64					82	
atrazine[6]	85.4	F400				64					84	
carbofuran[7]	61.5	WPH[2]			45					75		
carbofuran	53.9	WPH			70							90
alachlor[8]	43.6	F400	55		73		80	86				
alachlor	88.8	F400				59					74	
lindane	73.5	WPH			84			95				97
lindane	31.8	WPH	59		79		88			95		
heptachlor	7.0	WPH			53			86				97
2,4-D[9]	61.3	WPH			69			69				83
silvex	53.9	WPH			50			81				77

Notes:

1. In jar test of spiked Ohio River water with 15-20 mg/L alum; 2 min mix; 30 min flocculation; 60 min sedimentation, pH range = 7.5-8.3
2. Calgon WPH
3. Calgon Filtrasorb 400, 200 x 400 mesh
4. Single solute unless noted
5. With 98.4 ug/L linuron
6. With 69.1 ug/L linuron, 62.2 ug/L dinoseb, 77.6 ug/L benomyl
7. With 61.5 ug/L simazine
8. With 87.4 ug/L metolachlor
9. Acid form

of Wazeningen, the Netherlands. Rate and equilibrium experiments were performed to compare the rates of adsorption for flocculated and non-flocculated carbon. Norit FND-A-722 and Norit W-100 were the two types of PAC which were utilized. The coagulants included anionic (Superfloc A-150), nonionic (Superfloc N-100 and Magnofloc R-351) and cationic (Superfloc C-100) polyelectrolytes. The flocculation procedure involved the addition of a freshly prepared 500 mg/L polyelectrolyte solution to a well-stirred 10,000 mg/L carbon slurry. The rate experiments were performed in 2-liter baffled vessels. The adsorption equilibrium experiments were performed in batch, closed 250-mL vessels. Accurately weighed amounts of carbon with a fixed volume of adsorbate solution of known concentrations were subjected to a contact time of 24 hours or longer. The results of the experiments revealed that the 2,4-D loading on the flocculated carbon was higher than for nonflocculated carbon.

Tests were also performed using a continuously or intermittently stirred Upflow Flocculated Powered Carbon (UFPC) absorber.

The UFPC adsorber consisted of a vertical cylinder with a diameter of 7 cm and a height of 60 cm and filled with flocculated PAC. The solid phase loadings for both the adsorption isotherm (QI) and UFPC adsorber (Qu) are presented in Table 6-2. This data confirms that activated carbon effectively absorbs 2,4-D.

Croll (1974) evaluated several treatment options for the removal of acrylamide from water, including conventional treatment, oxidation with four different oxidants, and PAC. In the PAC experiments, a Thames River water sample was spiked with 6 ug/L of acrylamide and mixed with 8 mg/L of PAC. The solution, which had a pH of 5.0, was mixed for 30 minutes but only achieved a 13 percent removal.

Baker (1983) evaluated the performance of conventional treatment in combination with PAC at a water treatment plant in Bowling Green, Ohio. Alachlor and atrazine were two of the contaminants which were monitored. The conventional treatment involved alum coagulation, lime/caustic soda softening, recarbonation and filtration. Chemical dosages were not reported.
The following results were obtained for the raw water from the Maumee River and the plant finished water:

TABLE 6-2

2,4-D SOLID PHASE LOADING

Experiment Number	Initial Concentration (mg/L)	Flow Rate m/hr	Amount of PAC (grams)	Solid Phase Load (mg/g)					
				C/C_o=0.25		C/C_o=0.5		C/C_o=0.75	
				Qu[1]	QI[2]	Qu	QI	Qu	QI
1	24	2.6	50	79	88	92	97	121	103
2	19	2.4	50	74	86	85	95	93	100
3	24	2.4	150	106	88	118	97	128	103
4	11.2	4.8	150	98	77	108	88	126	92
5	16.2	4.8	150	105	84	127	92	139	97

Notes:

1. From upflow flocculated powdered carbon adsorber testing
2. Isotherm Testing

Carbon Concentration (mg/L)	Effluent Toxaphene Concentration (mg/L)	Percent Removal
0	0.30	0
1.0	0.18	40
2.0	0.16	47
3.0	0.085	72
6.0	0.058	81
9.0	0.014	95

Freundlich parameters of K = 160 mg/g and 1/n = 0.42 were obtained. The results indicate that PAC is effective for toxaphene removal.

Pilot-Scale:

Robeck, et al. (1965) evaluated a number of water treatment processes for pesticide removal. The pesticides that were studied included endrin, lindane, and the butoxy ethanol ester of 2,4,5-T. PAC was tested for various initial concentrations (1 to 10 ug/L) of pesticide in distilled water and Little Miami (Southwestern Ohio) River water. The distilled water was spiked with the proper concentration of pesticide, then PAC was added and mixed with the water. The river water was used in a pilot plant consisting of a constant-head tank, a 600-gallon pesticide mixing tank and two separate 20 gpm process trains. Each process consisted of a rapid-mix tank, flocculator, sedimentation tank, sand filter, coal filter, and two GAC beds (per train). PAC was added to the rapid-mix tank. The Little Miami River had the following water quality:

Parameter	Range
Turbidity (units)	5-250
Temperature (C)	2-27
pH (units)	7.3-8.5
Alkalinity (ppm as $CaCO_3$)	85-310
Hardness (ppm as $CaCO_3$)	130-330
COD (ppm)	5-35

Based on carbon adsorption isotherm data developed for the three pesticides, the results of the pilot study are presented below:

TABLE 6-3

TREATMENT OF SOCS BY POWDERED ACTIVATED CARBON

BOWLING GREEN, OHIO

SOC	Influent[1] Concentration ug/L	Percent Removal	Confidence Level	Sample Days
Carbon dose = 33 mg/L Hydrodarco B				
alachlor	0.97	94 ± 14	99.9	6
atrazine	2.39	87 ± 4	99.9	6
DIA[2]	0.10	100	99	5
simazine	0.24	100	99.8	6
Carbon dose = 18 mg/L Hydrodarco B				
alachlor	8.21	62 ± 11	99.9	6
carbofuran[3]	1.26	64 ± 16	99	6
atrazine	8.11	67 ± 11	99.9	6
DEA[4]	0.24	100	99.9	6
simazine	0.37	92 ± 13	99.9	6

Notes:

1. Influent to clarification process; carbon applied
2. DIA = deisopropyl atrazine (metabolite)
3. Removal also possibly affected by hyrolysis
4. DEA = deethyl atrazine (metabolite)

TABLE 6-4

TREATMENT OF SOCS BY POWDERED ACTIVATED CARBON

TIFFIN, OHIO

SOC	Concentration (ug/L)	Percent Removal	Confidence Level	Sample Days
Carbon dose = 11 mg/L Calgon WPH[1]				
alachlor	2.53	41 ± 6	99.9	6
carbofuran[2]	0.39	59 ± 29	98	6
atrazine	4.43	41 ± 8	99	6
DEA[3]	0.08	76 ± 25	98	4
simazine	0.26	63 ± 20	99	6
Carbon dose = 3.6 mg/L Calgon WPH[4]				
alachlor	1.49	36 ± 6	99.9	6
atrazine	2.61	38 ± 7	99	6
simazine	0.10	63 ± 7	99	6

Notes:

1. Applied to clarification process
2. Removal also possibly affected by hydrolysis
3. DEA = deethyl atrazine (metabolite)
4. Applied to filtration process

Activated carbon was chosen as the most feasible solution to the organics problem. Specifically, GAC treatment was recommended as a long term solution, however, PAC was chosen as a short-term solution. Preliminary laboratory isotherm studies indicated that PAC would be effective in attaining some reduction in contaminant concentration. A full-scale study was authorized to evaluate PAC while allowing the treatment plant to operate at full capacity. PAC was added at the wellfield to maximize contact time and improve the possibility of successful treatment. The pipeline from the wellfield to the treatment plant is 24 inches in diameter and 16,500 feet long. It was determined that a pipe velocity of 5 ft/sec would be required to keep the ICI Hydrodarco-B PAC in suspension. Since this corresponded to a total wellfield flow of 9 mgd, the average flow conditions of 10 mgd would be suitable.

The study evaluated the effectiveness of organic removal versus PAC dosage. The three PAC dosages that were evaluated included 30, 15, and 7.5 mg/L. The PAC contact time was estimated to be approximately two hours, including the time the water spent in the transmission line and in the upflow clarifiers. The actual PAC concentrations varied from those that were planned because of variations in plant flow and the difficulty of pacing the PAC feed with the actual flow. The PAC feed dosages for successive two-day periods were 7.9, 14.3, 26.6 and 7.1 mg/L. Increasing the PAC dosage increased the removal of the SOCs. However, since the PAC dosage had less of an impact on THM precursor removal, the low dosage of 7.1 mg/L was chosen for the plant. The results gathered over a 14-month period (March 1978 to May 1979) are presented in Table 6-5. The results indicate that PAC treatment ranged from being very effective to ineffective. Consistently good removals were obtained for dichlorobenzene and xylene. Percent removals were inconsistent for ethylbenzene, monochlorobenzene, and toluene, possibly due to short circuiting in the plant.

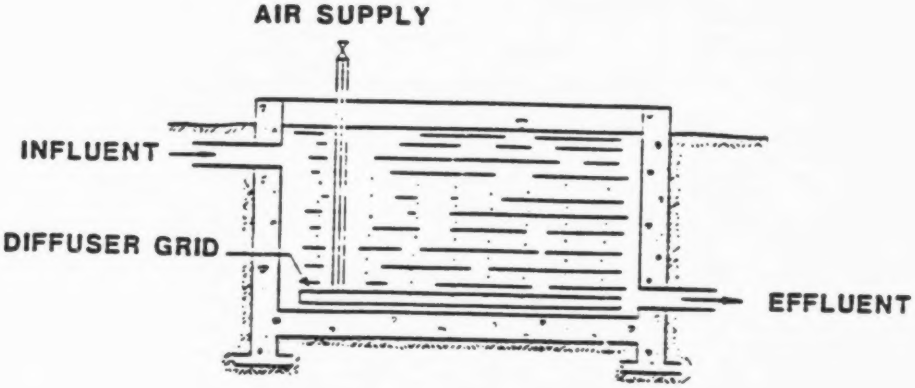
Diffused Aeration

Diffused aeration represents another method of applying aeration technology, which was found to be applicable for SOC removal. Diffused aeration implements the principles of aeration less efficiently than packed column aeration, however, diffused aeration may achieve removal of certain SOCs and may have limited applicability in locations which have certain constraints (e.g. hydraulic, space). In addition to the information presented on diffused

TABLE 6-5

PAC PERFORMANCE

Compound	Concentrations (ug/L) Influent	Concentrations (ug/L) Effluent	Percent Removal
Dichlorobenzene	0.08	0.05	38
	0.15	0.01	93
	0.14	0.017	88
	0.3	0.007	98
	0.4	0.02	95
Ethylbenzene	0.6	0.4	33
	0.3	0.2	33
Monochlorobenzene	1.1	0.8	27
	0.35	0.3	14
	1.0	0.1	90
	0.7	1.0	-
Toluene	0.5	0.5	0
	0.25	0.15	40
	0.2	0.1	50
	0.3	0.1	67
Xylenes	0.4	0.1	75
	0.11	0.01	91
	0.03	0.003	90
	0.5	0.2	60


AIR SUPPLY
INFLUENT
DIFFUSER GRID
EFFLUENT

DIFFUSED AIR BASIN

similar to those outlined in Section 5, Other Applicable Technologies, in which packed column aeration was discussed. The major difference is the substitution of contact time for the packing height parameter.

Treatability studies

Diffused aeration was evaluated in several bench scale studies involving many of the more volatile SOCs as well as two of the non-volatile SOCs.

Bench-Scale:

The EPA DWRD has reported on the treatment of several SOCs by diffused aeration (Miltner, December 1985b). Both distilled water and ground water were spiked with SOCs and used in the bench scale evaluations. The experimental apparatus was a countercurrent contactor with a stone sparger. The water flowrate through the system was 0.76 L/min, which resulted in a 13 minute contact time. The results for the test runs with distilled water are presented in Table 6-6; ground water results are presented in Table 6-7. The results indicate that the more volatile SOCs can be removed by aeration, while the less volatile compounds such as carbofuran and atrazine cannot be removed. In addition, the percent removal increased with increasing air to water ratio.

Love and Eilers (1982) performed several bench-scale diffused aeration tests to evaluate the removal of cis-1,2-dichloroethylene was from a contaminated ground water source in New Jersey. The glass column had a diameter of 4 cm (1.5 in) and a length of 1.2 m (4 ft) and equipped with a fitted glass diffuser at the bottom. The countercurrent air and water flows were controlled by rotameters. The column was operated at an air:water ratio of 4:1, a ten-minute contact time, and a water depth of 0.8 m (2.6 ft). The average influent concentration of 0.5 ug/L was reduced to less than 0.1 ug/L, a removal of greater than 80 percent. These results indicate that diffused aeration can remove cis-1,2-dichloroethylene from drinking water.

Ruggiero Engineers (1984) conducted counter-current diffused aeration testing on several organic compounds at Glen Cove, New York. Initial runs at an air:water ratio as high as 30:1 yielded effective cis-1,2-dichloroethylene removals. Greater than 50 percent removal was obtained for this compound even at an air:water ratio as low as 5:1. In general, the best removals occurred during the summer months when the water temperature was highest. Additional

TABLE 6-6

CONTROL OF SOCs IN DISTILLED WATER USING DIFFUSED AERATION[1]

SOC	Henry's Coefficient (atm)	Influent SOC Concentration (ug/L)	Percent Removal		
			Air-to-Water Ratio		
			5:1	10:1	15:1
cis-1,2-dichloroethylene	415	263	59	82	88
		196	57	69	73
		201	63	76	82
trans-1,2-dichloroethylene	361	217	85	96	97
		220	85	93	95
toluene	361	47	74[2]		
		130	59	74	79
		51	70	84	90
		51	70	86	90
		221	72	82	87
ethyl benzene	361	38	68[2]		
		135	73	84	90
		135	74	85	89
		199	75	84	88
chlorobenzene	254	97	67	85	90
		209	57	71	80
p-xylene	254	199	74	83	87
m-xylene	241	46	74[2]		
		117	58	75	79
		138	72	83	90
		138	73	86	89
		233	73	85	88
o-xylene	227	54	67[2]		
		121	48	67	73
		131	62	76	85
		131	65	79	84
		191	66	77	83

TABLE 6-6

CONTROL OF SOCs IN DISTILLED WATER USING DIFFUSED AERATION[1] (CONTINUED)

SOC	Henry's Coefficient (atm)	Influent SOC Concentration (ug/L)	Percent Removal Air-to-Water Ratio 5:1	10:1	15:1
1,2-dichloropropane	134	233	55	69	79
o-dichlorobenzene	107	125	46	63	77
		260	45	61	70
alachlor	11	139			12[2]
carbofuran	0.0005	79			20[2]
atrazine	0.0002	34			18[2]
		55	11[2]		5[2]

Notes:

1. Countercurrent flow, stainless steel sparger, water flow rate = .076 L/min., 13 min retention time
2. Denotes tests conducted using stone sparger

TABLE 6-7

TREATMENT OF SOCS IN SPIKED GROUND WATER[1] USING DIFFUSED AERATION[2]

SOC	Henry's Law Coefficient (atm)	Influent SOC Concentration (ug/L)	Percent Removals Air-to-Water Ratio 15:1
1,2-dichloropropane	134	122	77
cis-1,2-dichloroethylene	415	189	84
trans-1,2-dichloroethylene	361	124	92
toluene	361	108	87
ethyl benzene	361	113	88
chlorobenzene	254	119	85
p-xylene	254	103	88
m-xylene	241	107	84
o-xylene	227	120	82
o-dichlorobenzene	107	132	52
ethylene dibromide	54	125	50
lindane	0.021	107	2
carbofuran	0.0005	127	0
pentachlorophenol	0.0003	92	0
atrazine	0.0002	120	0
2,4-D[3]		132	0
silvex		77	0

Notes:

1. Great Miami Aquifer, Ohio
2. Countercurrent flow, water flow rate = 0.76 L/min, 13 min. retention time
3. Acid form

emergency treatment for volatile SOCs in a point of use application if the system were properly vented to remove off gases.

Oxidation

Several oxidants are available for removing SOCs from drinking water, including ozone, chlorine, chlorine dioxide, permanganate, hydrogen peroxide, and ultraviolet (UV) light, either by itself or in combination with any of the other oxidants. The mechanism for SOC removal by oxidation is the conversion of an SOC into either intermediate reaction products or carbon dioxide and water, which are the complete destruction products. Complete destruction is not always possible because the intermediates which are formed may be more resistant to further oxidation than the original SOC. In addition, these intermediates may in some cases, be more toxic than the original SOC.

Ozonation has been the most widely tested oxidant for the removal of SOCs from drinking water and, as such, will be discussed first. Additional oxidation technologies which have been evaluated for SOC removal will be presented after this subsection on oxidation. Since only limited data are available for SOC removal via oxidation, further evaluations are required before oxidation can be considered as an applicable technology.

Ozone-Process Description

Ozone was originally installed for disinfection purposes at a water treatment plant in France at the beginning of the 20th century. Since then, the number of ozone facilities for drinking water treatment has increased to about 3,000 worldwide in 1987. Although ozone has been employed for many years in Europe to improve drinking water quality, ozone technology in the U.S. is just beginning to gain acceptance as a viable water treatment option. Approximately 40 U.S. water treatment plants currently use ozone processes for disinfection, color destruction, taste and odor control, or THM precursor removal.

Recently, ozone has received more attention as a means of controlling SOCs in drinking water. The use of ozone in the U.S. for this purpose expected to increase in the future, spurred in part by changing regulations and also by technological advances which have increased the knowledge and understanding of ozone's capacity to remove organics from drinking water.

- Alkenes and aromatics react readily over a wide pH range -- implying removals occur by both oxidation mechanisms.
- Alkanes are oxidized at high pH only -- indicating oxidation by free radical mechanisms only.
- Ozonation in distilled and ground waters are similar, except at higher pHs, where radical scavengers such as bicarbonate ion may limit the removal of alkanes in natural waters.
- Increased ozone dosages improve reactions for all compounds except alkanes at low and neutral pH.
- Increasing contact time does not appreciably enhance alkane reactivity, whereas alkenes and aromatics are removed rapidly.

Ozone may also effect the removal of certain SOCs by oxidizing them into smaller molecules which are amenable to aeration or bioactivated carbon adsorption. The exact nature of ozone oxidation by-products are not known at the present time and present some concerns regarding their potential toxicity.

Equipment

A diagram of the ozone treatment process is illustrated on Figure 6-2. The major components of the system include an ozone production unit, a contact basin, an ozone destruction unit and associated valves and piping. The ozone production unit consists of gas handling, ozone generation, and cooling system components. The contact basin is design is based upon the raw water flow and required detention time. The ozone destruction unit eliminates any excess ozone before discharging to the atmosphere.

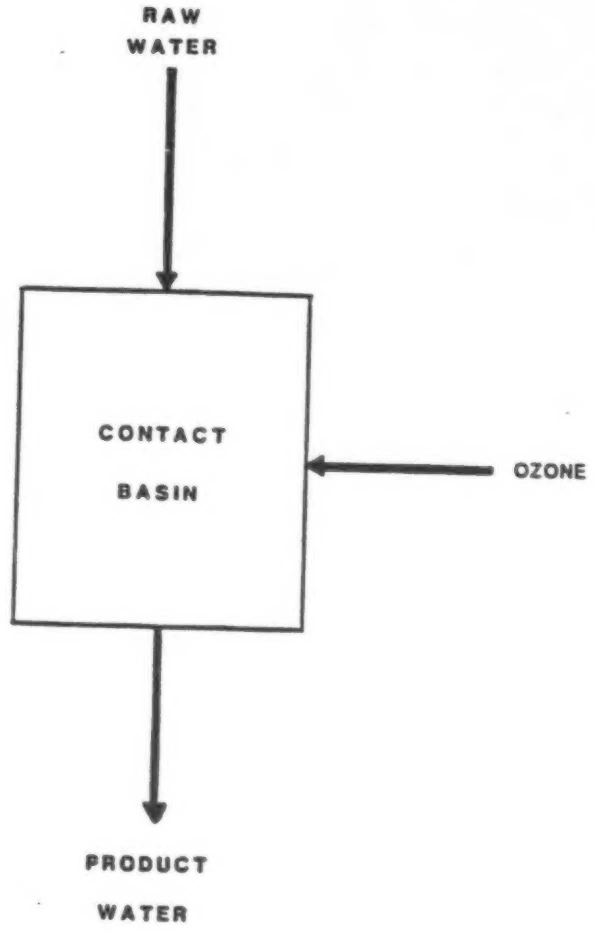
Treatability Studies

The majority of ozone treatability studies for SOC removal to date consist of bench scale evaluations. Ozone is typically applied to aqueous solutions of individual SOCs as either a gas or as a solution of ozone in water. The degree of SOC removal depends upon the type of SOC, the amounts of ozone applied and reacted, the ozone demand, pH, degree of mixing, and contact time.

Bench Scale:

The EPA DWRD has reported on the treatment of several SOCs by ozone oxidation (Miltner and Fronk 1985b; Fronk 1987a). Both distilled water and ground water were spiked with SOCs and used in the bench scale evaluations.

FIGURE 6-2


RAW
WATER
CONTACT
BASIN
OZONE
PRODUCT
WATER

OZONE OXIDATION
PROCESS SCHEMATIC

TABLE 6-8

TREATMENT OF SOCS IN DISTILLED WATER USING OZONATION[1]

SOC	pH[7]	SOC Concentration (ug/L)	Ozone[3,4] Dose (mg/L)	Percent Removal[2]	Ozone[3,5] Dose (mg/L)	Percent Removal[2]	Ozone[3,6] Dose (mg/L)	Percent Removal[2]
alkanes								
1,2-dichloropropane	3.95	314			3.7	0		
		237			6.0	6		
		267	0.5	0				
		272	0.4	0				
	9.85	257					11.4	87
	10.10	89	1.6	54			19.1	95
alkenes								
cis-1,2-dichloroethylene	3.95	267			3.7	90		
		234			6.0	89		
		234	0.5	99				
		236	0.4	82				
	9.85	217					11.4	94
trans-1,2-dichloroethylene	4.30	238					8.4	95
		164	0.4	100				
		201			6.4	100		
		167	1.4	100				
	9.10	158					8.4	98
aromatics								
toluene	4.20	159	1.7	70				
	4.60	190					12.0	98
		173	1.5	49				
		258			5.7	81	11.7	98
	9.15	190	1.7	72				
	9.20	149					11.5	98

TABLE 6-8

TREATMENT OF SOCS IN DISTILLED WATER USING OZONATION[1] (Continued)

SOC	pH[7]	SOC Concentration (ug/L)	Ozone[3,4] Dose (mg/L)	Percent Removal[2]	Ozone[3,5] Dose (mg/L)	Percent Removal[2]	Ozone[3,6] Dose (mg/L)	Percent Removal[2]
ethylbenzene	4.20	164	1.7	69				
	4.50	64					12.0	94
	4.60	195					12.0	95
		132	1.5	47				
		208			5.7	79	11.7	96
		105	2.5	93				
		126					9.1	95
	9.15	196	1.7	70				
	9.20	73					13.5	91
	9.20	107					11.5	93
chlorobenzene	4.30	226					8.4	99
		179	0.4	86				
		240			6.4	98		
		204	1.4	97				
	9.10	170					8.4	99
	10.10	75	1.6	96			19.1	100
p-xylene	4.50	59	2.0	98				
		100	2.5	95				
		120					9.1	97
	9.20	68					13.5	98
m-xylene	4.20	175	1.7	70				
	4.50	76					12.0	99
	4.60	208					12.0	97
		169	1.5	55				
		243			5.7	84	11.7	97
		109	2.5	95				
		132					9.1	97
	9.15	209	0.7	72				
	9.20	77					13.5	98
	9.20	145					11.5	97

TABLE 6-8

TREATMENT OF SOCS IN DISTILLED WATER USING OZONATION[1] (Continued)

SOC	pH[7]	SOC Concentration (ug/L)	Ozone[3,4] Dose (mg/L)	Percent Removal[2]	Ozone[3,5] Dose (mg/L)	Percent Removal[2]	Ozone[3,6] Dose (mg/L)	Percent Removal[2]
o-xylene	4.20	166	1.7	71				
	4.60	194					12.0	91
		190	1.5	54				
		265			5.7	84	11.7	98
	9.15	197	1.7	73				
	9.20	164					11.5	97
o-dichlorobenzene	4.50	95					12.0	91
		132	2.5	80				
		148					9.1	89
	9.20	97					13.5	90
others								
carbofuran		74					8.6	100
atrazine		27			4.6	99		
		55			7.1	70		
alachlor		139			6.9	95		

Notes:

1. Countercurrent flow, stone sparger, water flow rate = 0.76 L/min, 13 min contact time
2. Percent removal corrected for gas stripping
3. Ozone dose (mg O_3/L water) = applied ozone (mg O_3/L water) - off gas (mg O_3/L water)
4. Applied ozone = 0.5 to 2.5 mg O_3/L water
5. Applied ozone = 5 to 8 mg O_3/L water
6. Applied ozone = 18 to 24 mgO_3/L water
7. pH range = 5.8 to 7.4, unless adjusted to listed value

TABLE 6-9

CONTROL OF SOCS IN SPIKED WATER USING OZONATION[1,2]

SOC	pH[8]	Concentration (ug/L)	Ozone[3,4] Dose	Percent Removal[7]	Ozone[3,5] Dose	Percent Removal[7]	Ozone[3,6] Dose	Percent Removal[7]
alkanes								
ethylene dibromide		125			6.0	9		
		111	0.9	8				
		105	1.6	11			8.6	16
1,2-dichloropropane		122			6.0	18		
		112	0.9	8				
		98	1.6	7			8.6	24
	9.95	79			3.0	14	17.0	42
lindane		107	1.7	7	6.8	19		
alkenes								
cis-1,2-dichloroethylene		189	2.1	93			10.1	87
	9.75	165			3.5	78	19.0	98
trans-1,2-dichloroethylene		124			6.0	100		
		103	0.9	100				
		98	1.0	100			8.6	100
aromatics								
toluene		108	2.1	74			10.1	91
		7	1.6	80			9.4	100
ethyl benzene		113	2.1	73			10.1	90
		42	1.6	81			9.4	100
chlorobenzene		119			6.0	84		
		113			2.7	47		
	9.95	76			3.0	62	17.0	91
	10.10	86	1.6	96			19.1	100
p-xylene		103	2.1	84			10.1	93
		44	1.6	87			9.4	100

TABLE 6-9

CONTROL OF SOCS IN SPIKED WATER USING OZONATION (Continued)[1,2]

SOC	pH[8]	Concentration (ug/L)	Ozone[3,4] Dose	Percent Removal[7]	Ozone[3,5] Dose	Percent Removal[7]	Ozone[3,6] Dose	Percent Removal[7]
m-xylene		107	2.1	83			10.1	93
		46	1.6	93			9.4	100
o-xylene		120	2.1	82			10.1	93
		60	1.6	89			9.4	100
	9.75	73			3.5	71	19.0	89
o-dichlorobenzene		132	2.1	57			10.1	64
		96	1.6	77			9.4	98
	9.75	108			3.5	36	19.0	74
others								
carbofuran		127	1.6	100	7.5	96		
atrazine		117			2.8	49	8.6	76
alachlor		145			2.6	79	9.3	96
silvex		77	2.4	30			8.5	85
2,4-D[9]		132	1.5	58			8.1	79
pentachlorophenol		42			2.8	99	8.6	99

Notes:

1. Great Miami Aquifer, Ohio
2. Countercurrent flow, stone sparger, water flow rate = 0.76 L/min, 13 min contact time
3. Ozone dose (mg O_3/L water) = applied ozone (mg O_3/L water) - off gas (mg O_3/L water)
4. Ozone dose < 2.4 mg O_3/L water
5. Ozone dose = 3.0-7.5 mg O_3/L water
6. Ozone dose > 8.1 mg O_3/L water
7. Percent removal corrected for gas stripping
8. pH range = 7.6 to 8.2, unless adjusted to listed value
9. Acid form

TABLE 6-10

OZONE REACTION RATE CONSTANTS

SOC	SOC Conc (mM)[1]	pH	Reaction Rate Constant (L/Mole-sec)
Styrene	0.007	2	300,000
trans-1,2-Dichloroethylene	0.03-0.1	2	5,700
cis-1,2-Dichloroethylene	0.06-0.2	2	800
p-Xylene	0.2-0.5	2	140
m-Xylene	0.2-0.5	2	94
o-Xylene	0.03-0.8	1.7-5	90
Ethylbenzene	0.25-1	2	14
Toluene	0.4-4	1.7	14
Chlorobenzene	0.8-3	2	0.75
Tetrachloroethylene	0.7	2	0.1

Note:

1. millimoles/L (10^{-3} moles/L)

breakdown in a ten minute contact time at an ozone dosage of 0.5 mg/L. However, free radical reactions that may occur at higher pH values have not been considered.

Legube (1983) has investigated the mechanism of the reaction of ozone with soluble aromatic pollutants, including ethylbenzene, monochlorobenzene and styrene. The formation of breakdown products was also measured during these studies. Ozone gas was introduced into a 3 liter bubble column with solution recirculation. Analysis of ozone in the off gas permitted calculation of the ozone demand (ozone consumed/SOC removed) for each of the compounds. The removal attributable to air stripping was also assessed in separate experiments by bubbling air through the column at the same flowrate as ozone. Ethylbenzene and monochlorobenzene and consequently the ozone demand were both significantly removed by air stripping could not be estimated for these two SOCs. The results for the oxidation of styrene are presented below:

Initial Styrene Concentration	1.1×10^{-4} moles/L (11 mg/L)
pH	5.0
Ozone Application Rate	197 mg/hr at 12.8 L/hr
Ozone Demand (at zero percent styrene remaining)	0.9 moles ozone/mole styrene

Styrene oxidized to benzaldehyde and hydrogen peroxide, which might further react to form benzoic acid.

Gilbert (1979a) summarized the results from a number of researchers on the ability of ozone to remove several SOCs from drinking water. The results of this summary for the SOCs of concern are presented in Table 6-11. The results indicate that dichlorobenzene and heptachlor were completely removed by oxidation while heptachlor epoxide was only partially removed at an applied ozone dose of 17 ppm. Lindane was not appreciably removed until very high levels of ozone were applied. Neither heptachlor epoxide nor lindane appear amenable to ozonation. No assessment of the impact of air stripping was provided.

Buescher (1964) evaluated the effect of several oxidants, including ozone, on the removal of lindane from drinking water. Ozone gas was bubbled into aqueous solutions of lindane in a pyrex pipe with a diameter of 3 in and

TABLE 6-11

SOC REACTIVITY

SOC	Initial Concentration (mg/L)	Ozone Dose (mg/L)	Ozone Consumption (mg/L)	Percent Degredation
Dichlorobenzene	30	NR	60	100
Heptachlor	2	17	NR	100
Heptachlor epoxide	2	17	NR	26
Lindane	2	17	NR	0
Lindane	0.04-0.1	0.4-3	NR	0
Lindane	0.01	11	NR	10
Lindane	0.05	149	97	100

Source: Gilbert 1979

NR - Not Recorded

bench scale results these additional oxidation techniques have been evaluated for removing only a few of the SOCs from drinking water. Again, it is noted that an evaluation of breakdown products of any oxidation process should be made before considering oxidation for SOC removal.

Potassium Permanganate

The EPA DWRD has reported on the treatment of several SOCs by potassium permanganate oxidation (Miltner, December 1985). The results of bench scale testing using spiked distilled water are presented in Table 6-12. Permanganate dosages ranged from 8.7 to 11.4 mg/L and reaction times ranged from 22 to 29 hours. Trans- and cis-1,2-dichloroethylene, styrene, and heptachlor appear to be amenable to permanganate oxidation. Removals in excess of 84 percent were achieved for these four SOCs.

Potassium permanganate was used to oxidize trans and cis 1,2 dichloroethylene in bench scale testing using filtered Ohio River water and ground water from Landsdale, Pennsylvania. The results of this study are summarized in Table 6-13. These results indicate that the trans isomer is oxidized more rapidly than the cis isomer for similar permanganate dosages. The degree of removal for the cis isomer is also highly dependent on permanganate dose. Permanganate dosages of 0.5 and 2 mg/L achieved 10 and 80 percent removals, respectively, at the cis isomer at an initial concentration of 388 ug/L after 24 hours.

Chlorine

In bench scale testing using spiked Ohio River water, chlorine did not effectively oxidize alachlor, atrazine or carbofuran (Miltner, January 1989). Chlorine dosages ranged from 3 mg/L and 6 mg/L, and reaction times ranged from two to six hours. These results are presented below:

Pesticide	Concentration (ug/L)	Free Chlorine (mg/L)		Time (hr)	Percent Removal
		Dose	Residual		
Alachlor	31	6	4.9	5.83	- 5
Atrazine	65.8	6	1.3	5.33	2
Carbofuran	50.0	3	1.2	6	-11

Chlorine Dioxide

In bench scale testing using spiked Ohio River water, (Miltner, January 1989) alachlor, atrazine, and carbofuran were not oxidized by chlorine

TABLE 6-12

TREATMENT OF SOCS IN DISTILLED WATER WITH PERMANGANATE

SOC	Concentration (ug/L)	$MnO4^-$ (mg/L)	Time[1] (Hours)	Percent Removal
trans-1,2-dichloroethylene	140	10	22.75	100
cis-1,2-dichloroethylene	241	10	22.75	98
chlorobenzene	107	11.4	28.75	3
o-dichlorobenzene	139	11.4	28.75	4
1,2-dichloropropane	154	10	22.5	0
ethylene dibromide	248	10	24	7
toluene	171	10	22.75	11
styrene	140	10	24	93
ethyl benzene	197	10	22.75	10
o-xylene	139	10	22.75	12
m-xylene	134	10	22.75	13
p-xylene	156	10	22.75	5
alachlor	58	10	22.33	-22
carbofuran	109	10	(2)	32
carbofuran	37	10	(2)	13
lindane	100	10	22.5	-22
silvex	10	8.7	24	9
methoxychlor	24	10	22.5	-13
2,4-D	102	8.7	24	6
heptachlor	24	10	22.5	84

Notes:

1. Reaction stopped with thiosulfate or sulfite
2. Reaction stopped by SOC extraction at approximately 24 hours

TABLE 6-13

TREATMENT OF TRANS AND CIS 1,2-DICHLOROETHYLENE WITH PERMANGANATE

SOC	Concentration (ug/L)	MnO_4^- (mg/L)	Time (hrs)	Percent Removal
Ohio River				
trans	109	2	1	95
		2	4	100
cis	163	2	1	8
		2	4	25
		2	24	65
Landsdale, PA				
cis	388	2	1	15
		2	6	30
		2	24	80
cis	388	0.5	1	5
		0.5	6	6
		0.5	24	10

TABLE 6-14

TREATMENT OF SOCS IN DISTILLED WATER WITH HYDROGEN PEROXIDE[1]

SOC	Concentration ug/L	H_2O_2 mg/L	Time[2] Hours	Percent Removal
cis-1,2-dichlorethylene	213	8.5	25	-9
	107	8.5	23.5	-2
trans-1,2-dichloroethylene	201	8.5	25	-2
	161	7.9	21	-11
1,2-dichloropropane	126	7.9	21	-2
ethyl benzene	80	8.1	24	11
	73	8.0	24	-6
carbofuran	109	10.0	(3)	3
	37	10.0	(3)	2
toluene	79	11.0	26	20
o-xylene	93	12.4	26.5	-24
	47	11.0	26	14
m-xylene	141	8.1	24	11
	129	8.0	24	-5
	49	11.0	26	19
p-xylene	98	12.4	26.5	-2
chlorobenzene	231	8.5	25	-6
o-dichlorobenzene	124	8.5	23.5	2
ethylene dibromide	206	10.0	24	-13
methoxychlor	24	10.0	22.5	-16
alachlo.	58	10.0	22.33	-6
2,4-D[4]	85	9.1	24	10
silvex	7.9	9.1	24	7

Notes:

1. Reaction in dark at 20 C
2. Reaction stopped with thiosulfate or sulfite
3. Reaction stopped by SOC extraction at approximately 24 hours
4. Acid form

TABLE 6-15

TREATMENT OF SOCS BY ULTRAVIOLET IRRADIATION [1]

SOC	SOC Concentration (ug/L)[2]	Contact Time (min)	Percent Removal
cis-1,2-dichloroethylene	47.5[3]	2.25	73
cis-1,2-dichloroethylene	53.0	1.5	87
		2.25	94
		5.0	95
toluene	51.7	2.25	69
chlorobenzene	10.2	1.5	93
		2.25	100
		5.0	100
o-dichlorobenzene	4.0	1.5	100
		2.25	100
		5.0	100
ethylene dibromide	13.2	1.5	61
		2.25	80
		5.0	100

Notes:

1. flow-through cell; 28°C; UV intensity J85 uwatt/cm^2 at cell wall
2. Testing performed in distilled water unless otherwise noted.
3. Elkhart, Indiana ground water.

TABLE 6-16

TREATMENT OF SOCS BY ULTRAVIOLET IRRADIATION AND HYDROGEN PEROXIDE[1]

SOC	SOC Concentration (ug/L)[2]	Percent Removal by UV	H_2O_2 Concentration (mg/L)	Percent Removal by UV+H_2O_2
cis-1,2-dichloroethylene	53.0	94	10	94
cis-1,2-dichloroethylene	47.5[3]	73	8.8	92
toluene	51.7	69	10	100
chlorobenzene	10.2	100	10	99
o-dichlorobenzene	4.0	100	10	100
ethylene dibromide	13.2	80	10	78

Notes:

1. flow-through cell; 2.25 min contact time; 28°C; UV intensity 85 uwatt/cm^2 at cell wall.
2. Testing performed in distilled water unless otherwise noted.
3. Elkhart, Indiana ground water.

Arisman (1980) evaluated the use of UV/ozone for the removal of PCB at the General Electric Capacitor Products Department in Hudson Falls, New York. A 75 gallon pilot plant with thirty 40 watt lamps was used to treat industrial effluent containing PCBs. Ozone gas was diffused through the unit by gas spargers. A summary of the results of this study are presented below:

Flowrate	0.8-3.5 L/min
Influent Concentration	7-42 ug/L
Effluent Concentration	0-4.2 ug/L

No other effluent characteristics were given, nor was the effectiveness of UV/ozone compared to the effectiveness of ozone or UV alone.

Ozone/Hydrogen Peroxide

Bench scale tests for the removal of tetrachloroethylene (PCE) and trichloroethylene (TCE) were conducted by Glaze and Kang, 1988. Batch tests were run in a 70 liter reacter spiked with approximately 50 and 500 ug/L of PCE and TCE, respectively. The initial alkalinity of the source water was 200 mg/L as $CaCO_3$ and the TOC was 1.1 mg/L. The results of the ozone versus ozone/hydrogen peroxide system are shown below:

Dosage Required for 95 Percent Removal of TCE and PCE

Process	Ozone (mg/L)		Hydrogen Peroxide (mg/L)	
	TCE	PCE	TCE	PCE
Ozone(1)	9	33	0	0
Ozone/Hydrogen Peroxide	4	12	2	8

Notes:

1. Ozone dosage 15 mg/min, pH -8.0
2. Ozone dosage 15 mg/min, Hydrogen Peroxide dosage - 10 mg/min.

Ozone and hydrogen peroxide accelerates the oxidation of TCE by a factor of two to three and the oxidation of PCE by a factor of two to six depending on the ozone dosage. Due to an apparent mass transfer effect, increasing the hydrogen peroxide dosage rate beyond a certain level does not increase the oxidation rate of TCE and PCE.

TABLE 6-17

RESULTS OF OZONE AND HYDROGEN PEROXIDE PILOT STUDY

Influent			TCE (ug/L)			PCE (ug/L)		
Alkalinity mg as $CaCO_3$/L	TOC mg/L	pH	Influent	Effluent	Percent Removal	Influent	Effluent	Percent Removal
268	<0.1	7.25	142	40	72	15	6.3	58
270	<0.1	7.55	132	39	90	14	5.5	61
270	<0.1	7.30	117	18	85	12	3.1	74
NA	NA	7.25	122	17	86	13	3.1	76
268	<0.1	7.50	123	34	72	14	4.9	65
271	<0.1	7.55	140	20	86	14	3.8	73
273	<0.1	7.55	143	12	92	16	3.0	81
NA	NA	7.35	106	8.5	92	10	2.0	80
NA	NA	7.30	133	6.3	95	14	1.7	88
NA	NA	7.35	136	5.6	96	14	1.7	88
275	<0.1	7.50	107	7.4	93	12	2.3	81
275	<0.1	7.45	128	9	93	15	2.5	83
275	<0.1	7.30	130	24	82	13	3.9	70
270	<0.1	NA	136	11	92	15	2.8	81
NA	NA	7.50	133	24	82	14	5.0	64
270	<0.1	7.50	125	31	75	14	5.1	64
272	<0.1	7.45	136	27	80	15	4.7	69
266	<0.1	7.30	123	20	84	12	3.4	72
270	<0.1	7.45	114	57	50	11	6.5	41
268	<0.1	7.30	130	42	68	14	5.9	58

Notes:

1. Contact Time was 15 minutes.
2. NA means data was not analyzed.

as recovered product water. The remainder washes the rejected salts from the membrane surfaces and is discharged as a concentrated stream.

While RO primarily has been used in desalination, it has been used to remove certain SOCs generally those whose molecular weights are greater than 120, from drinking water. This removal may not be due to rejection, but possibly to SOC adsorption onto the membrane. Continued adsorption may lead to membrane poisoning, and consequently membrane replacement, because SOC desorption is generally difficult and usually entails destruction of the membrane. In addition, membrane leakage due to sporadic desorption and/or permeation has been shown to occur.

The performance of an RO system for SOC removal depends upon a number of factors including pH, turbidity, iron/manganese content of the raw water, and membrane type. Pretreatment is sometimes required to prevent fouling of the membrane system. Design of a pretreatment system is dependent upon the quality and quantity of the feed water source. Pretreatment for reverse osmosis may include one or more of the following: pH adjustment, filtration and addition scale prevention chemicals. Existing treatment plants may already provide much of the pretreatment required, for example, coagulation/filtration for highly turbid surface waters or iron removal for well waters. Reverse osmosis may be particularly appropriate for small systems where the total volume of waste concentrate is low.

Blending of treated water and raw water to produce a mixed finished water of acceptable quality may be a factor in selecting a reverse osmosis system because reverse osmosis systems generally produce high quality water. Blending, while site specific, is more economical than treating all of the raw water. The fraction of the raw water to be treated will depend upon the SOC removal efficiency of the selected reverse osmosis membrane and the SOC concentration in the raw water.

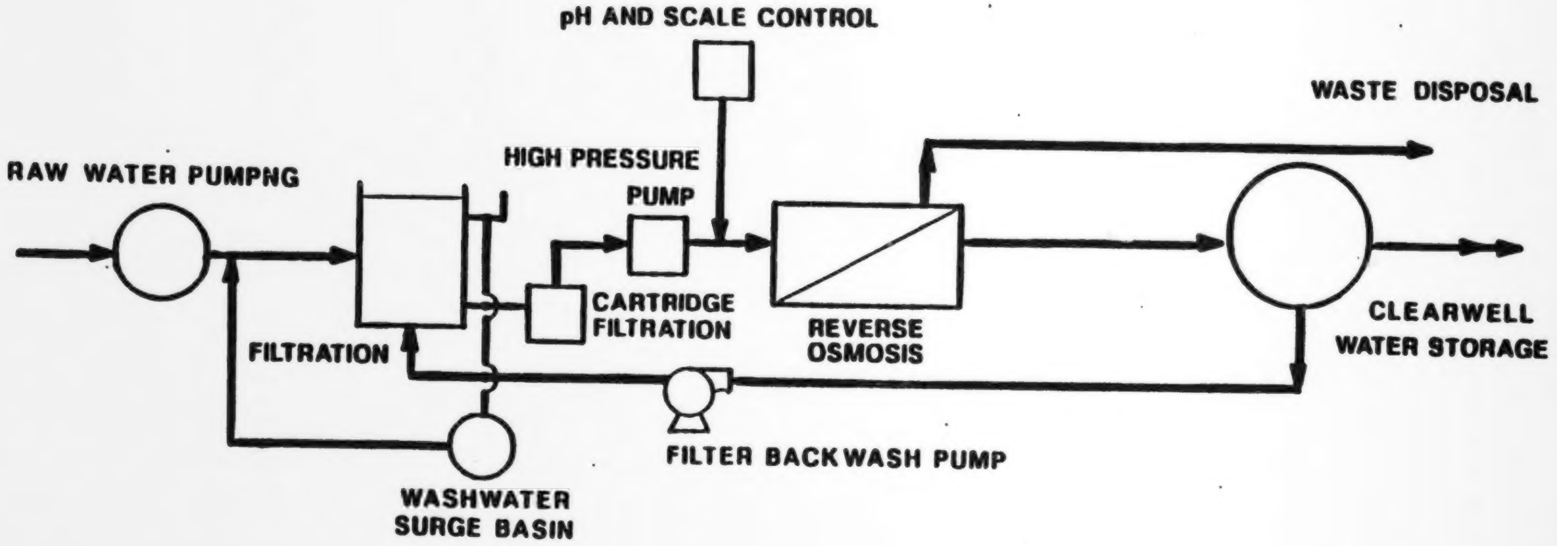
Equipment

A typical process schematic for a reverse osmosis treatment plant is illustrated on Figure 6-3. The major components of this system include:

1. Provision for prefiltration including polymer feed system, provisions for backwashing and backwash water storage

2. Storage and feed facilities for pH and scale control

FIGURE 6-3


pH AND SCALE CONTROL
WASTE DISPOSAL
RAW WATER PUMPNG
HIGH PRESSURE PUMP
CARTRIDGE FILTRATION
REVERSE OSMOSIS
CLEARWELL WATER STORAGE
FILTRATION
FILTER BACKWASH PUMP
WASHWATER SURGE BASIN

REVERSE OSMOSIS TREATMENT PLANT

TABLE 6-18

REMOVAL OF SOCs BY VARIOUS REVERSE OSMOSIS MEMBRANES

SOCs	Molecular Weight	Percent Removal: Cellulose Acetate	Percent Removal: Polyamide	Percent Removal: Thin Film Composites A	Percent Removal: Thin Film Composites B	Percent Removal: Thin Film Composites C
1,2-Dichloropropane	113	10	61	90	-	-
Cis-1,2-dichloroethylene	97	0	19	14	12	32
Trans 1,2-dichloroethlene	97	20	0	30	-	-
Toluene	92	10	-	-	-	-
Ethylbenzene	106	34	-	-	-	-
O-xylene	106	9	-	-	-	-
P-xylene	106	22	-	-	-	-
Chlorobenzene	112	-	-	50	54	87
O-dichlorobenzene	147	-	-	65	-	-
Ethylene dibromide	188	-	-	35	-	-
Alachlor	270	-	-	100	-	-

Notes:

1. Influent concentration range 6-153 ug/L.
2. Average of distilled and ground water tests.
3. - denotes that tests were not conducted.
4. See Table 6-20 for operational conditions.

TABLE 6-19

REVERSE OSMOSIS MEAN OPERATIONAL CONDITIONS[1]

Membrane	Cellulose Acetate	Nylon Amide	Thin Film Composite A	Thin Film Composite B	Thin Film Composite C
Type	SW[2]	HF[3]	SW	SW	SW
Surface Area, m^2	1.8	276	1.9	1.9	1.6
Operating Pressure, psi	235	150	200	200	200
Reject, L/min	4.7	4.9	9.5	9.4	9.5
Permeate, L/min	0.4	1.1	1.5	0.6	0.5
Feed, L/min	5.1	6.0	11.0	10.0	10.0
Percent Recovery	8	18	14	6	5
Time to Steady State, hrs	1	1	3-14 13	5-46	21
Time of Operation, hrs	13	13	16 284	257	182
TDS Percent Rejection	95	92	99 99	94	98

Notes:

1. for data presented in Table 6-19
2. SW - spiral wound
3. HF - hollow fiber

TABLE 6-20

TREATMENT OF SOCS IN GROUND WATER [1] USING REVERSE OSMOSIS [2]

SOC	Concentration (ug/L)	Mean Percent Removal						
		Cellulose Acetate[3]	Nylon Amide[4]	Thin Film Composite[3]				
				A	B	C	D	E
1,2-dichloropropane	24	4	75	50	38	88	79	38
aldicarb sulfoxide	39	99	99	99	97	99	99	95
aldicarb sulfone	47	94	96	98	96	99	99	94
carbofuran	14	86	99	99	99	99	99	99
feed, (L/min)		2.2	2.6	1.0	1.3	1.35	2.2	1.2
percent recovery		6	50	10	13	10	5	16
pH of water[5]		5.2	5.5	5.6	4.6	4.9	4.8	4.9
specific conductance[6] (umhos/cm)		43	38	36	23	15	19	30

Notes:

1. Suffolk County, New York
2. membrane diameter 2 to 4 inches
3. spiral wound membrane
4. hollow fiber membrane
5. pH of feed water = 5.6
6. specific conductance of feed water = 551 umhos/cm

until 40 percent of the test solution had passed through the membrane. The following results were obtained for atrazine:

Membrane Type	Percent Removal of Atrazine
Cellulose Acetate	84.0
NS-100	97.9

The results indicate that reverse osmosis is effective for atrazine removal from water. Proper membrane selection can ensure maximum removal. The degree to which atrazine is adsorbed into the membrane should be evaluated.

Malaiyandi, et al. (1980) evaluated a reverse osmosis system for removing lindane from aqueous solution at the Environmental Health Directorate in Ottawa, Canada. Raw water with an initial lindane concnetration of 6.8 to 8.0 mg/L was fed into radial flow, all-stainless steel RO cells with CA-316 cellulose acetate membranes. The flow rate into the RO system was 1.5 mL/min, which corresponded to a system pressure of 6,200 to 6,900 K Pa(900-1,000psi). A recovery of 20 percent was obtained. 225 mL of feed solution was sent through the RO system and 25-mL aliquots of both feed and permeate were sampled for analysis at the end of each run. Procedures were also carried out to strip lindane from the cellulose acetate membrane to quantify the amount of lindane which was retained by the membrane. The distribution (percent) of the lindane was:

Recycled Feed	36
Product Water	24
Membrane	40
TOTAL	100

Lindane removal by in-situ stripping proved to be very difficult. Destructive analysis of the RO membrane provided the most reliable estimate of the amount of lindane absorbed onto the membrane.

Edwards and Schubert (1974) evaluated the selectivity of four RO membranes for several derivatives of 2,4-D in aqueous solution. The membrane tests were performed in batches in a commercial ultra filtration cell with a capacity of 150 mL, an effective membrane area of 27.5 cm^2, and a magnetic stirring bar mounted near the membrane surface. The ultrafiltration cell was filled with 70 mL of 50 ug/L solution of the sodium salt of 2,4-D and closed

The results indicate fairly good removals for lindane at the two higher concentrations.

Pilot Scale:

Regunathan, et al. (1983) evaluated the performance of two point-of-use treatment devices in removing various organic, inorganic, microbiological, and particulate contaminants from potable water. One device consisted of a reverse osmosis unit, prefilter, and two GAC beds. The device was field tested in Miami, Florida for the removal of THMs and other organics, including endrin, methoxychlor, and lindane. The ground water had the following water quality:

pH	7.4
TDS (mg/L)	625
Alkalinity (HCO_3^-)	160
Sodium (mg/L)	120
Sulfate (mg/L)	230
Chloride (mg/L)	12
Silicate (mg/L SiO_2)	5

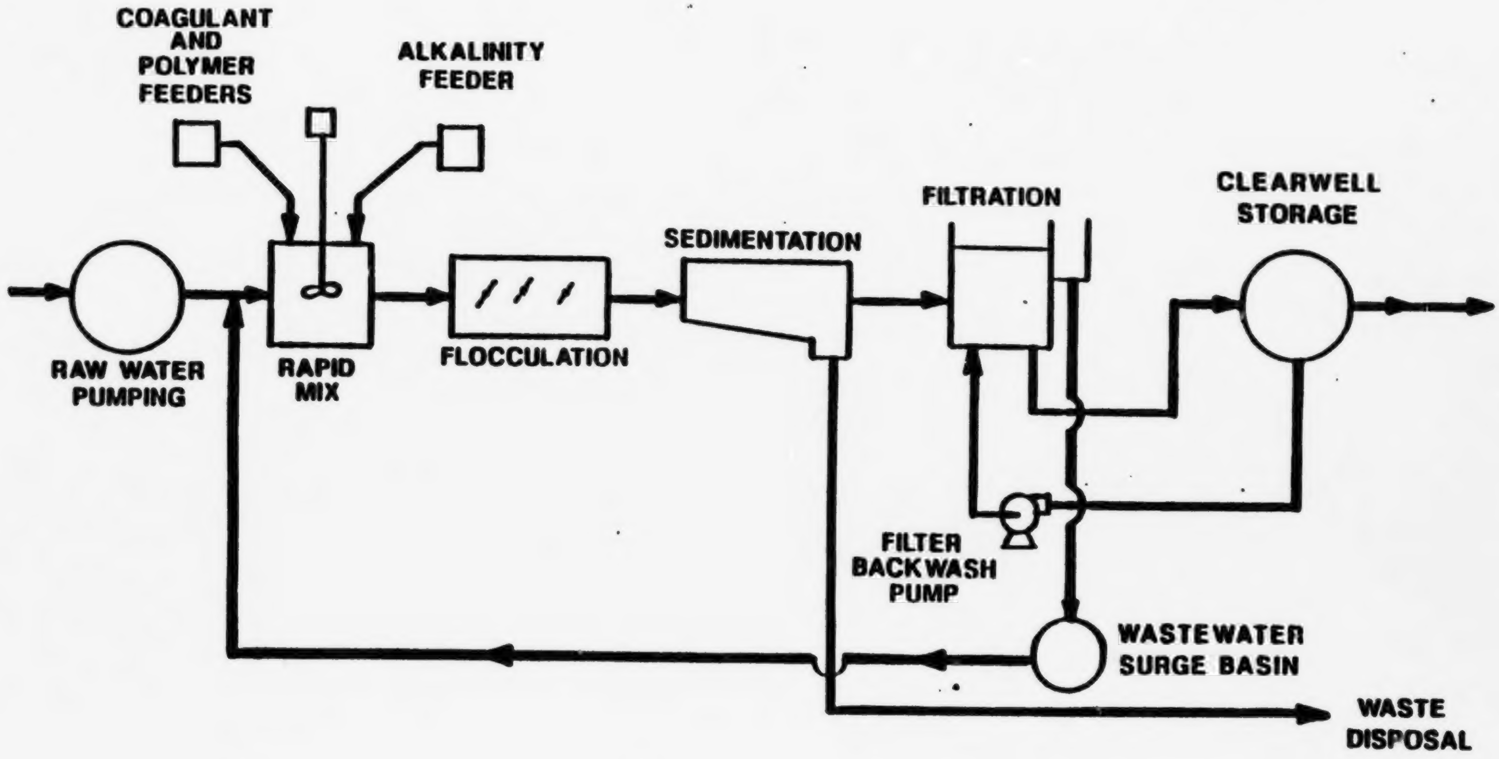
The results of this pilot study are summarized below:

		Percent Removal	
Compound	Influent Concentration (ug/L)	RO Unit Membrane	Overall
Endrin	2	J90	99-100
Methoxychlor	1,000	J90	99-100
Lindane	40	40	99-100

The RO device effectively removed endrin and methoxychlor. However, the role of the GAC filters was extremely important in the overall effectiveness of the device.

A modified RO-carbon device was also tested for its ability to remove PCB (Aroclor 1242). The small carbon adsorber was used with the RO membrane because PCB is strongly adsorbed. An average influent PCB concentration of 105 ug/L was reduced by more than 95 percent by the RO membrane alone and at least 99.7 percent by the entire device. The results indicate that reverse osmosis may be an effective treatment method for PCB removal.

The studies which have been presented here indicate that reverse osmosis has potential as a removal method for SOCs. However, these studies are very limited in both the level of which testing has been performed and the contaminants used for testing. In addition, there are several disadvantages


COAGULANT AND POLYMER FEEDERS
ALKALINITY FEEDER
RAW WATER PUMPING
RAPID MIX
FLOCCULATION
SEDIMENTATION
FILTRATION
CLEARWELL STORAGE
FILTER BACKWASH PUMP
WASTEWATER SURGE BASIN
WASTE DISPOSAL

CONVENTIONAL TREATMENT PLANT

FIGURE 6-4

SOCs which are actually present in the raw water. In addition, the American Water Works Association Research Committee on coagulation has published recommendations and comments on the conventional treatment process.

Bench Scale:

The EPA DWRD has reported the results of bench scale conventional treatment of several SOCs (Miltner, January 1989). Jar tests were performed with alum, on spiked Ohio River water. The results of these tests are presented in Table 6-21. The data indicates that these pesticides are not strongly sorbed onto particles or complexed with humic substances that are in turn sorbed to particulates, because particulate control processes provided minimal or no control.

Croll, et al. (1974) evaluated conventional treatment processes for acrylamide removal. The process train consisted of alum coagulation, sedimentation and rapid sand gravity filtration, all of which were simulated in bench-scale tests. Several 400-ml samples of Thames River water, which had a pH of 7.5 and contained 25 mg/L kaolin suspension, were coagulated with an alum dosage of 32 mg/L. A polymer containing 0.19 percent acrylamide by weight was also added at a dosage of 2 mg/L. The samples were rapid mixed and allowed to settle for 15 minutes. The supernatant was filtered at a liquid loading rate of 2 gpm/sf through a sand bed which had a 2.5 cm diameter of and a deoth of 30 cm. A removal of only seven percent of the original acrylamide was obtained. This removal indicates that conventional treatment is ineffective for acrylamide removal.

Steiner and Singley (1979) evaluated the coagulation/filtration and softening processes for removal of methoxychlor. Jar testing was performed on Gainesville, Florida tap water which had the following modified water quality parameters:

pH (units)	8.00
Total hardness as $CaCO_3$	100 mg/L
Calcium hardness as $CaCO_3$	52 mg/L
Magnesium hardness as $CaCO_3$	48 mg/L
Alkalinity as $CaCO_3$	42 mg/L
Total dissolved solids	190 mg/L

The initial methoxychlor concentrations were 1, 5, and 10 mg/L. In the coagulation/filtration phase of the study, the turbidity of the raw water

TABLE 6-21

JAR TESTING OF SPIKED OHIO RIVER WATER(1,2)

Pesticide	Influent Concentration (ug/L)	Dose (mg/L)	Turbidity (NTU)	Percent Removed
Alachlor	43.6	15	42	4
Atrazine	65.7	20	7	0
Carbofuran	93.2	30	18	-8

Note:

1. Raw water pH ranged from 7.5 - 8.3
2. Settled water turbidities below 1 NTU
3. Technical grade $Al_2(SO_4)_3 \cdot 14H_2O$

TABLE 6-22

METHOXYCHLOR REMOVAL

Effect of pH

pH	Methoxychlor Residual[1] (mg/L) Alum	Methoxychlor Residual[1] (mg/L) Ferric Sulfate
8.5	0.730	0.722
8.0	0.671	0.698
7.5	0.421	0.383
7.0	0.366	0.417
6.5	0.320	0.403
6.0	0.303	0.342
5.5	0.593	0.290
5.0	0.595	0.319
4.5	0.535	0.286

Effect of Initial Turbidity

Coagulant[2]	Intitial Methoxychlor Concentration (mg/L)	Methoxychlor Residual (mg/L) Initial Turbidity 23 NTU	Methoxychlor Residual (mg/L) Intitial Turbidity 58 NTU
Alum	1	0.265	0.201
	5	0.668	0.320
	10	0.702	0.539
Ferric sulfate	1	0.258	0.173
	5	0.342	0.220
	10	0.381	0.279

Notes:

1. Initial concentration of methoxychlor was 5 mg/L
2. Tests were performed at pH = 6

TABLE 6-23

METHOXYCHLOR REMOVAL VIA LIME SOFTENING

Initial Methoxychlor Concentration (mg/L)	Softening pH	Methoxychlor Residual (mg/L)	Percent Removal	Hardness[1] Initial	Final
1	9.5	0.400	60	188[2]	144
5	9.5	2.622	48	188	144
10	9.5	3.260	67	188	144
1	10.5	0.379	62	188	100
5	10.5	1.303	74	188	100
10	10.5	1.342	87	188	100
1	11.0	0.217	78	192[3]	70
5	11.0	0.257	95	192	70
10	11.0	0.297	97	192	70
1	11.3	0.160	84	192	64
5	11.3	0.205	96	192	64
10	11.3	0.297	97	192	64

Notes:

1. Hardness expressed as mg/L $CaCO_3$
2. Initial hardness increased from 100 to 188 mg/L via calcium chloride addition
3. Initial hardness increased from 100 to 192 mg/L by the addition of magnesium and calcium

magnesium hydroxide ($MgOH_2$), a gelatinous compound, is one possibility for the improved performance at higher pH values.

Aly and Faust (1965) examined the effect of several water treatment processes, including coagulation/sedimentation, on the removal of four 2,4-D derivatives and their parent compound 2,4-dichlorophenol (2,4-DCP). The four derivatives included the sodium salt of 2,4-D and the isopropyl, butyl and isoctylesters of 2,4-D. Each compound had an initial concentration of 1 mg/L. Alum or ferric sulfate were added at dosages at 100 mg/L. The samples were rapidly mixed at a pH of 7.4 and were allowed to settle for 30 minutes.

The following results were obtained:

Compound	Percent Removal
2,4-DCP	0
Sodium salt of 2,4-D	0
2,4-D butylester	2.0
2,4-D isoctylester	2.9
2,4-D ispropylester	3.0

The results indicate that conventional treatment consisting of coagulation and sedimentation is not effective for the removal of 2,4-D from water without suspended material.

Cohen et al. (1960, 1961) published a three part report on the effects of fish poisons in water supplies. Toxaphene was one of the compounds that was studied. Cohen et al. (1960) examined toxaphene removal by a number of processes, including alum coagulation. Treatment of unspecified initial concentrations of toxaphene with alum dosages as high as 100 mg/L did not reduce the concentration significantly. No data were provided on the actual testing. Alum coagulation was not effective in removing toxaphene, or any of the other fish poisons, from water.

Cohen et al. (1961) examined the impact of a number of water treatment processes on toxaphene odor removal. Once again, alum coagulation was tested. No significant impact on odor was observed at an alum dosage of 90 mg/L.

Huang (1972) evaluated the effect of lime coagulation on the removal of several pesticides, including endrin and lindane. At an unspecified lime dosage, solutions containing initial endrin and lindane concentrations of 10 mg/L were reduced by 35 and less than 10 percent, respectively. This water treatment plants on these rivers. The Tiffin, Ohio water treatment plant uses alum coagulation-flocculation, sedimentation, and filtration in its conventional treatment system. A summary of the results for an entire series of summer sampling dates is shown below:

Compound	Concentration Ranges (ug/L)	
	Influent	Effluent
Alachlor	0.5-5.0	0.2-2.0
Atrazine	1.0-8.0	1.0-8.0

The data indicated that as the raw water concentrations increased, the corresponding finished water concentrations increased as well. On several occasions, the influent levels were actually less than effluent levels. The removals obtained for alachlor and atrazine were generally less than 50 and 10 percent, respectively. These results suggest that the conventional water treatment processes of coagulation-flocculation, sedimentation and filtration are not effective for removing alachlor and atrazine from drinking water.

Additional information from three water treatment plants in northwestern Ohio (Fremont, Bowling Green, and Tiffin) supports the previous conclusion that alachlor and atrazine are not effectively removed by conventional treatment (Miltner, January 1989). Percent removals of 24 and 14 were achieved for alachlor and atrazine, respectively. Full scale data indicate little removal of these two compounds across a conventional treatment plant. Data from the Fremont and Bowling Green plants indicate the effectiveness of softening in removing carbofuran. At influent carbofuran concentrations ranging from 0.49 to 1.62 ug/L, 100 percent removal was achieved at a pH of 10.9. The Tiffin plant, which utilizes chlorination but not softening, obtained 54 percent removal at a pH of 7.9.

Singley et al. (1979) evaluated the use of PAC, as well as complementary process such as aeration and improved coagulation, for removal of synthetic organic chemicals in two studies at Florida water treatment plants. One study was performed at the Sunny Isles Water Treatment Plant, which is one of three facilities serving the city of North Miami Beach, Florida. This plant has a design capacity of 12.8 mgd, but usually treats an average flow of 10 mgd. It is a conventional lime softening plant utilizing three upflow clarifiers. Nalco 8173, an anionic polymer, is the coagulant which is utilized. After

Des Moines, Iowa. The water for this plant is obtained from the Racoon River (40 percent) and an infiltration gallery (60 percent). Data on atrazine concentrations at various locations are presented below:

Location	Atrazine (mg/L)
Racoon River	25
Infiltration Gallery	82
Blended Influent	59
Prefilter	47
Finished Water	29
Finished Water (60-L composite sample)	60
Finished Water (16-L grab sample)	71

These results indicate that conventional treatment processes are not effective for the removal of atrazine from water.

Nicholson, et al. (1966) reported that a conventional water treatment process consisting of coagulation, sedimentation and filtration had little effect on reducing toxaphene concentrations at the plant. The influent toxaphene concentrations at the plant did not exceed 0.41 ug/L.

AWWA Research Committee on Coagulation (1979)

Following a recap of several coagulation/sedimentation/filtration (i.e. conventional treatment) studies on bench, pilot, and full scale levels, the AWWA Research Committee on Coagulation included the following general comments/conclusions:

- The removal of pesticides (including lindane, toxaphene, 2,4-D, and others) will depend upon the degree of association between the pesticides and the natural organic content of the water.
- If a strong association exists, the best removals of pesticides will occur at pH values between 5 and 6 for alum and pH values between 4 and 5 for iron coagulants.
- The pH is an important variable during the coagulation process.
- To date, studies on the removal of pesticides have inadequately described the influence of coagulation pH on process performance.

7. COSTS

The purpose of this section of the document is to develop costs for GAC and packed column aeration treatment facilities for removing SOCs from drinking water. As described in Section 3, these are the two technologies that have been identified as being applicable treatment methods for SOC removal. The basis for costs and design assumptions are explained below.

Basis for Costs

Capital, operation and maintenance (O&M), and total costs (in cents per 1,000 gallons) were developed for GAC and packed column facilities for water supply systems of several sizes. The design and production capacities of these systems which serve different ranges of population are presented in Table 7-1. Costs for GAC facilities were developed using the following sources:

- WATER COST: A computer program for Estimating Water and Wastewater Treatment Costs. Culp. Wesner.Culp., Santa Ana, California.
- "Estimation of Small System Water Treatment Costs," Gumerman, R.C., Burris, B.E., and Hansen S.P. USEPA Contract No. 68-03-3093, 1984.
- "Estimating Water Treatment Costs - Volume 2," Gumerman, R.C., Culp, R.L., and Hansen, S.P. USEPA Contract No. 68-03-2516, EPA-600/2-79-162b, 1979.

Packed column aeration costs were developed by the Technical Support Division of the Office of Drinking Water, USEPA, using an in-house computer model (Cummins, 1988). The basis of this model has been presented by Cummins and Westrick (1986).

All costs presented in this document are in late 1987 dollars. The capital costs were updated using indices specific to the major cost components of the construction cost. The Bureau of Labor Statistics (BLS) and Engineering News Record (ENR) indices which were used to update the capital costs are presented in Table 7-2. The Producers Price Index for Finished Goods was used to update the cost of maintenance materials, which are a component in the operation and maintenance cost. This index is also presented in Table 7-2. Other unit cost and general cost considerations are listed in Table 7-3. For the purpose of estimating costs per 1,000 gallons, the capital costs were

TABLE 7-1

PLANT DESIGN CAPACITIES AND AVERAGE FLOWS

Population Category	Population	Average Flow (MGD)	Design Capacity (MGD)
25 - 100	57	0.0056	0.024
101 - 500	225	0.024	0.087
501 - 1,000	750	0.086	0.27
1,001 - 3,300	1,910	0.23	0.65
3,301 - 10,000	5,500	0.70	1.8
10,001 - 25,000	15,500	2.1	4.8
25,001 - 50,000	35,000	5.0	11.0
50,001 - 75,000	60,000	8.8	18.0
75,001 - 100,000	88,100	13.0	26.0
100,001 - 500,000	175,000	27.0	51.0
500,001 - 1,000,000	730,000	120.0	210.0
Greater than 1,000,000	1,550,000	270.0	430.0

TABLE 7-2

COST INDICES FOR LATE 1987

Description	Index Reference	Numerical Value
General Purpose Machinery	BLS 114	330.2
Concrete	BLS 132	343.3
Steel	BLS 1017	357.4
Skilled Labor	ENR U.S. Average	401.8
Pipe & Valves	BLS 1149	354.2
Electrical	BLS 117	261.2
Housing	ENR Building Cost	378.2
Housing	$/Sq Ft	150.0
Producer Price Index		296.7
Construction Cost Index		412.4

TABLE 7-3

GENERAL ASSUMPTIONS USED IN DEVELOPING TREATMENT COSTS

Electric Power	$ 0.086/Kwh
Labor - Small System Sizes (<100,000 gpd)	$ 5.90/hr
Large System Sizes (>100,000 gpd)	$ 14.30/hr
Diesel Fuel	$ 0.80/gal
Natural Gas	$ 0.0027/scf
Sitework	15% of construction costs
Contractor's Overhead & Profit	12% of construction costs (including sitework)
Contingencies	15% of construction costs
Engineering & Technical Fee	15% of construction costs (including sitework & contractor's O&P)
Interest Rate	10%
Number of Years	20

Capital and operating costs for the contactor, initial carbon charge and backwash pumps were estimated using the cost model and manuals cited above. These costs were based on facility size and were independent of the SOC being considered. A spreadsheet was used to develop the carbon replacement/regeneration costs for each SOC based on its usage rates. Costs from the model and spreadsheet were then added to obtain the final facility costs. The overall approach to developing GAC facility costs is explained in the flow-chart illustrated in Appendix E.

The design parameters used to estimate the costs for contactor, carbon charge and backwash pumps are shown in Table 7-4. The following assumptions were used for design purposes:

- The contactors were sized to provide an empty bed contact time (EBCT) of 10 ~~7.5~~ minutes at the design flow, but would have an operating EBCT of greater than 15 minutes based on the average flow. ~~except for the last three flow categories.~~

- Systems with a design flow of less than 1 MGD used package pressure contactors.

- Systems with a design flow of 1 MGD - 11 MGD used pressure contactor.

- Systems with a design flow larger than 11 MGD used concrete gravity contactors.

- Housing requirements assumed contactors were totally enclosed, with additional area for pipe galleries and operating and maintenance service area.

- Electrical energy for building heating, cooling, ventilation and lighting was 25 Kwh/sq ft of building area per year.

- Maintenance material costs were estimated for general supplies, pumps, instrumentation repair, valve replacement or repair, and other miscellaneous work items.

- Costs for land, raw water pumping, chlorination, bulk potable water storage, finished water pumping and waste disposal were not included.

The individual capital and O&M costs for the contactors, initial carbon charge and backwash pumps are presented in Table 7-5.

The following assumptions were used for estimating the carbon replacement/regeneration costs:

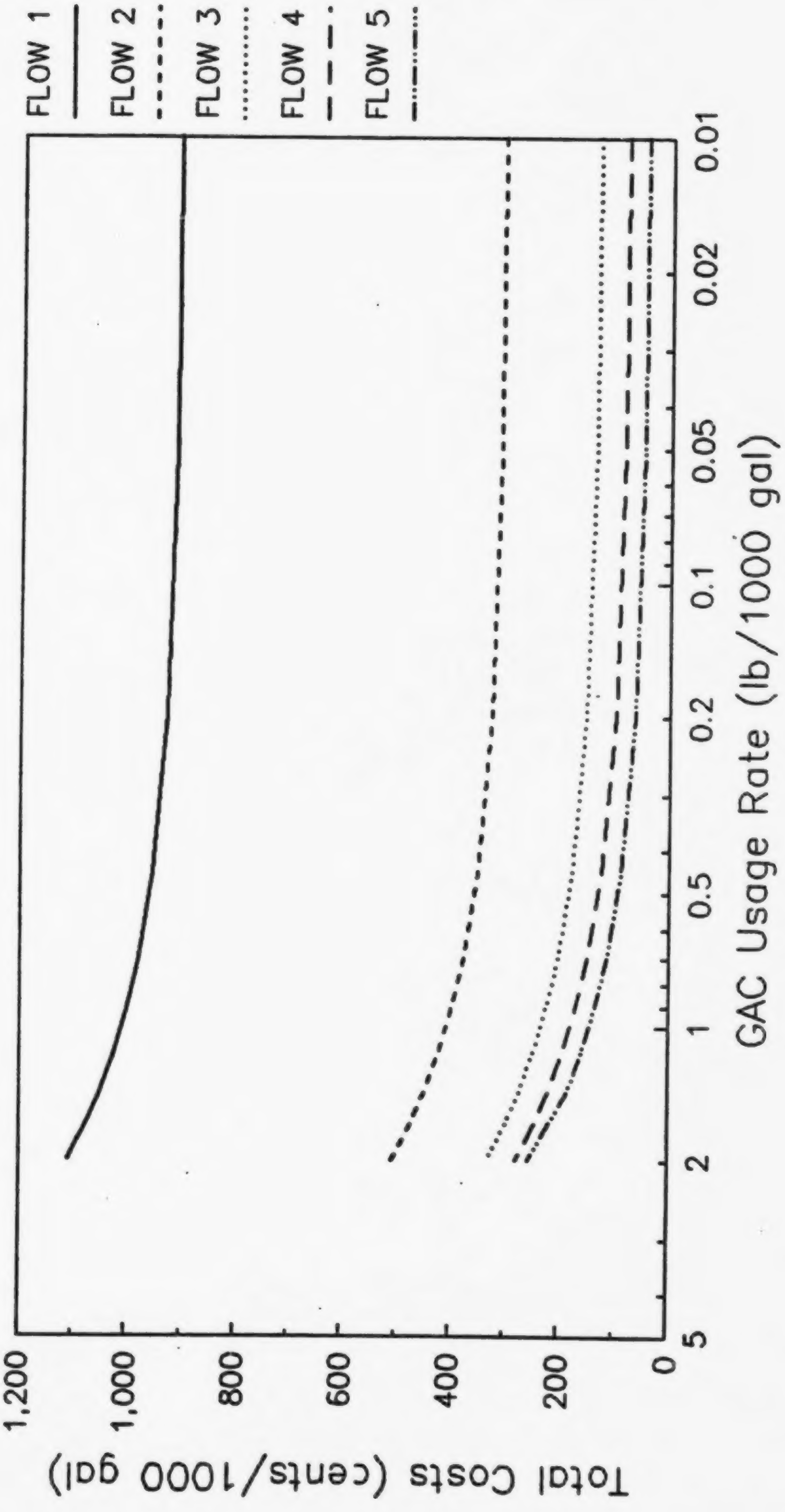
Table 7-4
GAC System Design Parameters

Population Range Design Flow (MGD) Average Daily Flow (MGD)	Contactor Type	EBCT (min)		Number of Units	Volume of Each Unit (cu.ft)	Area of Contactor (sq.ft)	Total Carbon Charge (lbs)	Backwash Pump Size (gpm)	Number of Backwash Pumps
		Design	Operating						
25-100 0.024 0.0056	Package Pressure	7.5	32.1	1	17	3.4	500	50	1
101-500 0.087 0.024	Package Pressure	7.5	27.2	1	60	12	1700	180	1
501-1,000 0.27 0.086	Package Pressure	7.5	23.5	1	190	38	5300	570	1
1,001-3,000 0.65 0.23	Package Pressure	7.5	21.2	1	450	90	12600	1350	1
3,001-10,000 1.8 0.7	Pressure	7.5	19.3	4	310	62	35000	1000	2
10,001-25,000 4.8 2.1	Pressure	7.5	17.1	6	550	110	93300	1670	2
25,001-50,000 11 5	Pressure	7.5	16.5	14	550	110	214000	1670	2
50,001-75,000 18 8.8	Concrete Gravity	7.5	15.3	4	3125	625	350000	9000	2
75,001-100,000 26 13	Concrete Gravity	7.5	15.0	6	3000	600	505600	9000	2
100,001-500,000 51 27	Concrete Gravity	7.5	14.2	10	3550	700	991700	10000	2
500,001-1,000,000 210 120	Concrete Gravity	7.5	13.1	30	4860	975	4083300	10000	6
>1,000,000 430 270	Concrete Gravity	7.5	11.9	50	6000	1200	8361000	10000	8

Table 7-5
Base Costs for GAC Contactor, Carbon Charge and Backwash Pump

Population Range Design Flow (MGD) Average Daily Flow (MGD)	Construction Cost ($)			Total Construction Cost ($)	(2) Capital Cost ($)	O&M Cost ($/yr)		
	Contactor	Carbon Charge	BW Pump			Contactor	BW Pump	Total
25-100 0.024 0.0056	--	--	--	44000	87000	--	--	1500
101-500 0.087 0.024	--	--	--	67000	140000	--	--	1900
501-1,000 0.27 0.086	--	--	--	110000	220000	--	--	2700
1,001-3,000 0.65 0.23	--	--	--	180000	370000	--	--	4000
3,001-10,000 1.8 0.7	310000	38000	59000	410000	670000	36000	700	37000
10,001-25,000 4.8 2.1	730000	97000	72000	900000	1500000	47000	1200	48000
25,001-50,000 11 5	1600000	200000	72000	1900000	3100000	73000	3000	76000
50,001-75,000 18 8.8	1500000	320000	170000	2000000	3300000	52000	3000	55000
75,001-100,000 26 13	1900000	460000	160000	2500000	4200000	65000	3500	69000
100,001-500,000 51 27	3200000	880000	180000	4300000	7200000	110000	4100	110000
500,001-1,000,000 210 120	9400000	3300000	410000	13000000	22000000	410000	10000	420000
>1,000,000 430 270	17000000	6600000	500000	24000000	43000000	820000	19000	840000

FIGURE 7-1


Total Costs (cents/1000 gal)
1,200
1,000
800
600
400
200
0
GAC Usage Rate (lb/1000 gal)
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
FLOW 1
FLOW 2
FLOW 3
FLOW 4
FLOW 5

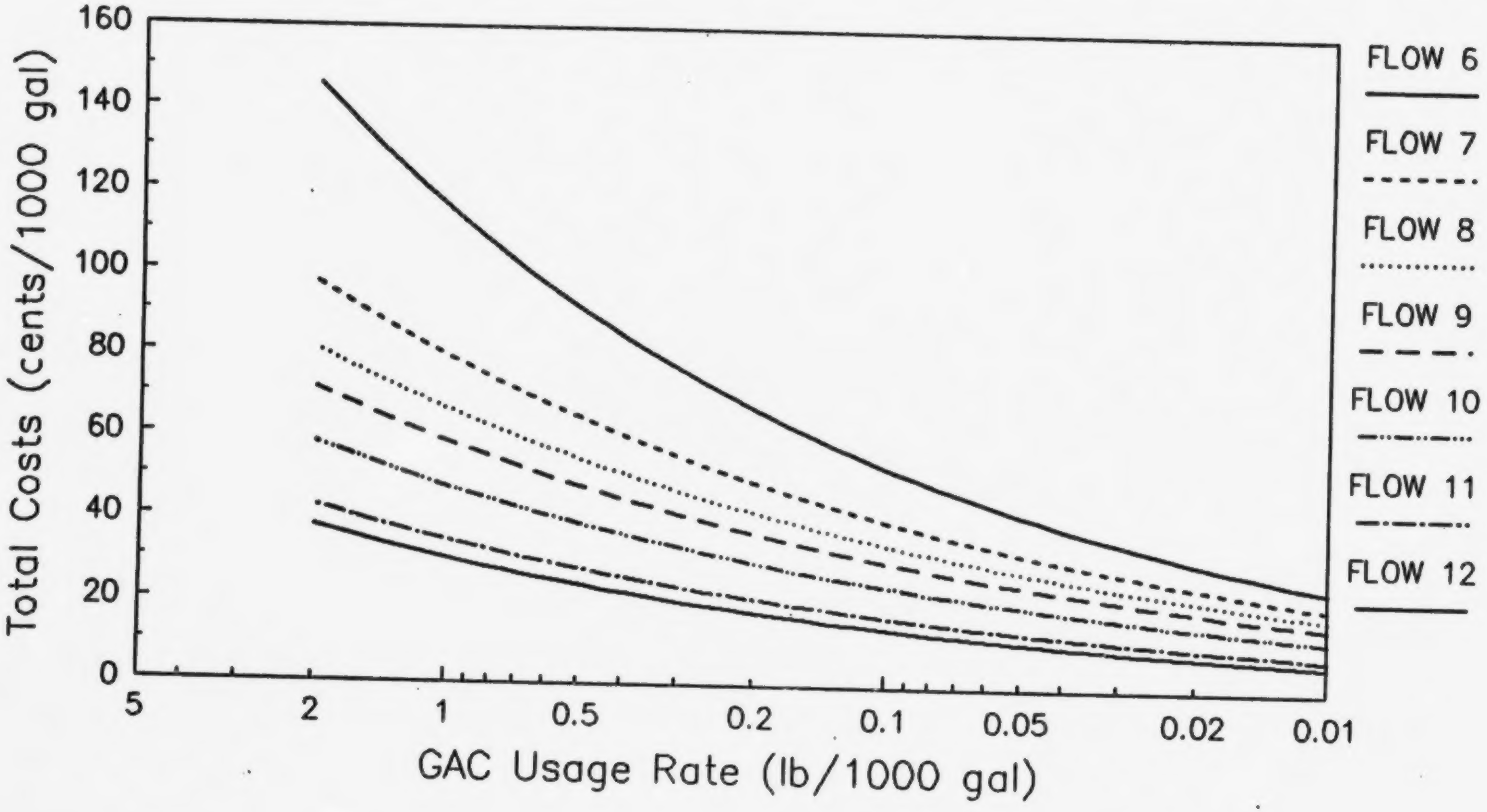

Total Costs (cents/1000 gal)
160
140
120
100
80
60
40
20
0
GAC Usage Rate (lb/1000 gal)
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
FLOW 6
FLOW 7
FLOW 8
FLOW 9
FLOW 10
FLOW 11
FLOW 12

FIGURE 7-2

TABLE 7-6

PHASE II CARBON USAGE COSTS

Population Range Design Flow (MGD) Average Daily Flow (MGD)	Carbon Usage Rate (lbs/1,000 gallons)	< 0.1	0.1-0.3	0.3-0.6	0.6-0.8	0.8-1.0	1.0-1.3	1.3-1.5	1.5-1.8	1.8-2.0
25-100	Total Capital Cost (K$)	125	125	125	125	125	125	125	125	125
0.024	O&M Cost (K$/year)	4	4	5	5	6	6	7	7	8
0.0056	Total Production Cost (cents/1,000 gal)	910	930	950	980	1000	1020	1050	1070	1100
101-500	Total Capital Cost (K$)	190	190	190	190	190	190	190	190	190
0.087	O&M Cost (K$/year)	5	7	9	11	13	15	17	19	22
0.024	Total Production Cost (cents/1,000 gal)	310	330	350	380	400	420	450	470	500
501-1,000	Total Capital Cost (K$)	300	300	300	300	300	300	300	300	300
0.27	O&M Cost (K$/year)	8	13	21	29	35	43	51	59	66
0.086	Total Production Cost (cents/1,000 gal)	140	150	180	200	220	250	270	300	320
1,001-3,300	Total Capital Cost (K$)	480	480	480	480	480	480	480	480	480
0.65	O&M Cost (K$/year)	14	27	48	69	85	107	128	149	170
0.23	Total Production Cost (cents/1,000 gal)	80	100	120	150	170	190	220	240	270
3,301-10,000	Total Capital Cost (K$)	800	800	800	800	800	800	800	2900	3000
1.8	O&M Cost (K$/year)	30	70	130	200	250	310	380	270	290
0.7	Total Production Cost (cents/1,000 gal)	49	64	89	110	130	160	180	240	250
10,001-25,000	Total Capital Cost (K$)	1700	1700	1700	4000	4200	4500	4700	4900	5100
4.8	O&M Cost (K$/year)	70	190	380	320	370	430	480	540	590
2.1	Total Production Cost (cents/1,000 gal)	36	51	76	103	113	124	135	145	155
25,001-50,000	Total Capital Cost (K$)	3300	3300	6000	6600	6900	7300	7600	7900	8200
11.0	O&M Cost (K$/year)	130	400	340	450	540	640	740	840	940
5.0	Total Production Cost (cents/1,000 gal)	29	44	58	67	74	82	90	97	104
50,001-75,000	Total Capital Cost (K$)	5100	7500	8500	9200	9600	10000	11000	11000	11000
18.0	O&M Cost (K$/year)	200	300	500	700	800	1000	1200	1300	1500
8.8	Total Production Cost (cents/1,000 gal)	25	37	47	55	61	68	75	82	88
75,001-100,000	Total Capital Cost (K$)	6500	9400	10000	11000	12000	12000	13000	13000	14000
26.0	O&M Cost (K$/year)	300	400	700	1000	1200	1400	1600	1900	2100
13.0	Total Production Cost (cents/1,000 gal)	23	32	41	48	54	60	67	73	79
100,001-500,000	Total Capital Cost (K$)	13000	14000	16000	17000	18000	19000	19000	20000	21000
51.0	O&M Cost (K$/year)	400	700	1300	1800	2200	2600	3100	3600	4000
27.0	Total Production Cost (cents/1,000 gal)	19	25	32	38	43	49	55	60	65
500,001-1,000,000	Total Capital Cost (K$)	36000	39000	42000	44000	46000	47000	48000	49000	50000
210.0	O&M Cost (K$/year)	1200	2600	4700	6700	8300	10000	12000	14000	16000
120.0	Total Production Cost (cents/1,000 gal)	12	16	22	27	31	36	41	45	50
>1,000,000	Total Capital Cost (K$)	63000	67000	71000	74000	76000	79000	81000	82000	84000
430.0	O&M Cost (K$/year)	2600	5400	9900	14000	18000	22000	26000	30000	34000
270.0	Total Production Cost (cents/1,000 gal)	10	14	19	23	27	31	36	40	44

Packed Column Aeration

The major components of a packed column aeration facility are:

- Column structure
- Internals
- Packing
- Blower(s)
- Clearwell
- Booster pump(s)
- Piping

In addition, there may be other site-specific capital cost components such as:

- Special sitework
- Raw water holding tank
- New/restaged well pump
- Blower building
- Booster pump building
- Chemical facility
- Noise control installation
- Air emissions control

The key design criteria used to size the packed column facilities are presented in Table 7-7. The following assumptions were utilized for the purpose of developing preliminary packed column cost estimates:

- Henry's Law Coefficients for 16 SOCs are presented in Table 7-8. The henry's coefficients for heptachlor and toxaphene have not been proven in pilot sutdies. Additional data is required before these compounds can be classified as definately strippable.

- Tower design was based on a maximum liquid loading rate of 30 gpm/sf, and a minimum air pressure drop gradient of 50 $Nm^{-2}m^{-1}$.

- The maximum packed tower diameter was 16 feet. Multiple units were used in instances where a diameter greater than 16 feet was required.

- A dumped packing material was used.

- Column shell was constructed of 1/4 inch 304 stainless steel walls with 1/2 inch thick by 3-inch wide flanges.

TABLE 7-7

PACKED COLUMN DESIGN PARAMETERS

Ground water temperature	12 Degrees C
Column shell construction	304 stainless steel
Packing Material	1 inch plastic saddles
Air Well	Concrete
Maximum column diameter	16 ft
Maximum liquid loading	30 gpm ft^2
Minimum Air Gradient	50N $m^{-2}m^{-1}$
Safety factor for Henry's coefficient[1]	1.1
Safety factor for K_1a	1.1

Note:

[1] Safety factor is applied to henry's coefficient estimated using pilot data.

TABLE 7-8

HENRY'S LAW COEFFICIENTS USED TO ESTIMATE EQUIPMENT SIZE AND COSTS FOR PACKED COLUMN AERATION

Compound	Henry's Coefficient (atm)	Source(1)(2)
monochlorobenzene	75	Pilot at Riviera Beach, FL
cis-1,2-dichloroethylene	83	Pilot at 10 field sites
dibromochloropropane	7	50%(vapor pressure/solubility)
ethylene dibromide	17	50%(vapor pressure/solubility)
ethyl benzene	174	Pilot at Bastrop, LA
m-xylene	137	Pilot at Bastrop, LA
o-dichlorobenzene	39	Pilot at Dedham, MA
o-xylene	125	Pilot at Bastrop, LA
p-xylene	150	Pilot at Bastrop, LA
sytrene	63	50%(vapor pressure/solubility)
trans-1,2-dichloroethylene	150	Experimental Data(3)
tetrachloroethylene	274	Field data
toluene	162	Pilot at Bastrop, LA
1,2-dichloropropane	54	Pilot at Dedham, MA
~~Toxaphene~~	136	Experimental data(3)
~~Heptachlor~~	42	Experimental data(3)

Notes:

1. Henry's constant estimated from vapor pressure and solubility data used a safety factor of 50 percent (Cummins, 1988).

2. Henry's Law Coefficient estimated from pilot testing were reported by Cummins and Westrick (1987).

3. Henry's-coefficient based on experimental data (Warner, Cohen, and Ireland, 1980). Adjusted to reflect henry's coefficient at 12 C.

TABLE 7 - 9

Estimated Cost for Removing Monochlorobenzene Using Packed Column Aeration - March 1989

ystem Size Category ilation Range ign Flow (MGD) erage Daily Flow (MGD)		Influent								
		100. ug/L			600. ug/L			1000. ug/L		
		Effluent (ug/L)			Effluent (ug/L)			Effluent (ug/L)		
		60.	100.	400.	60.	100.	400.	60.	100.	400.
	Percent Removed	40.			90.	83.	33.	94.	90.	60.
25-100	Total Capital Cost (K$)	15.	----	----	22.	20.	15.	24.	22.	17.
0.024	O&M Cost (K$/Year)	0.2	----	----	0.4	0.4	0.2	0.5	0.4	0.3
0.0056	Total Production Cost (cents/1,000 gal)	98.	----	----	150.	130.	96.	160.	150.	110.
101-500	Total Capital Cost (K$)	27.	----	----	41.	38.	27.	45.	41.	31.
0.087	O&M Cost (K$/Year)	0.7	----	----	1.2	1.1	0.6	1.3	1.2	0.8
0.024	Total Production Cost (cents/1,000 gal)	44.	----	----	69.	62.	43.	75.	69.	51.
501-1,000	Total Capital Cost (K$)	42.	----	----	68.	60.	41.	76.	68.	48.
0.27	O&M Cost (K$/Year)	1.4	----	----	2.6	2.3	1.4	2.9	2.6	1.7
0.086	Total Production Cost (cents/1,000 gal)	20.	----	----	34.	30.	20.	38.	34.	23.
1,001-3,000	Total Capital Cost (K$)	65.	----	----	110.	96.	62.	120.	110.	74.
0.65	O&M Cost (K$/Year)	3.0	----	----	5.5	4.8	2.9	6.1	5.5	3.5
0.23	Total Production Cost (cents/1,000 gal)	13.	----	----	22.	19.	12.	25.	22.	15.
3,001-10,000	Total Capital Cost (K$)	120.	----	----	210.	180.	110.	240.	210.	140.
1.8	O&M Cost (K$/Year)	7.8	----	----	14.	13.	7.5	16.	14.	9.2
0.70	Total Production Cost (cents/1,000 gal)	9.4	----	----	15.	13.	8.0	17.	15.	9.9
10,001-25,000	Total Capital Cost (K$)	230.	----	----	440.	380.	220.	500.	440.	280.
4.8	O&M Cost (K$/Year)	21.	----	----	38.	34.	21.	42.	38.	25.
2.1	Total Production Cost (cents/1,000 gal)	6.4	----	----	12.	10.	6.1	13.	12.	7.5
25,001-50,000	Total Capital Cost (K$)	460.	----	----	880.	750.	430.	1000.	880.	550.
11.	O&M Cost (K$/Year)	50.	----	----	89.	79.	49.	99.	89.	58.
5.0	Total Production Cost (cents/1,000 gal)	5.7	----	----	11.	9.1	5.4	12.	11.	6.7
50,001-75,000	Total Capital Cost (K$)	710.	----	----	1400.	1200.	670.	1600.	1400.	860.
18.	O&M Cost (K$/Year)	86.	----	----	150.	130.	84.	170.	150.	99.
8.8	Total Production Cost (cents/1,000 gal)	5.3	----	----	9.9	8.5	5.1	11.	9.9	6.2
75,001-100,000	Total Capital Cost (K$)	990.	----	----	2000.	1700.	940.	2300.	2000.	1200.
26.	O&M Cost (K$/Year)	130.	----	----	220.	200.	120.	250.	220.	150.
13.	Total Production Cost (cents/1,000 gal)	5.1	----	----	9.6	8.3	4.9	11.	9.6	6.1
0,001-500,000	Total Capital Cost (K$)	1800.	----	----	3800.	3100.	1700.	4400.	3900.	2200.
51.	O&M Cost (K$/Year)	260.	----	----	460.	400.	250.	510.	460.	300.
27.	Total Production Cost (cents/1,000 gal)	4.8	----	----	9.1	7.8	4.6	10.	9.1	5.7
0,001-1,000,000	Total Capital Cost (K$)	6500.	----	----	14000.	12000.	6100.	17000.	14000.	8100.
210.	O&M Cost (K$/Year)	1200.	----	----	2000.	1800.	1200.	2300.	2000.	1400.
120.	Total Production Cost (cents/1,000 gal)	4.5	----	----	8.5	7.3	4.4	9.6	8.5	5.4
>1,000,000	Total Capital Cost (K$)	13000.	----	----	29000.	23000.	12000.	33000.	29000.	16000.
430.	O&M Cost (K$/Year)	2900.	----	----	4600.	4100.	2800.	5100.	4600.	3200.
270.	Total Production Cost (cents/1,000 gal)	4.4	----	----	8.1	7.0	4.2	9.1	8.1	5.2

TABLE 7 - 10

Estimated Cost for Removing cis-1,2-Dichloroethylene Using Packed Column Aeration - March 1989

System Size Category Population Range Design Flow (MGD) Average Daily Flow (MGD)		Influent								
		50. ug/L			100. ug/L			200. ug/L		
		Effluent (ug/L)			Effluent (ug/L)			Effluent (ug/L)		
		5.0	70.	100.	5.0	70.	100.	5.0	70.	100.
	Percent Removed	90.			95.	30.		97.5	65.	50.
25-100	Total Capital Cost (K$)	21.	----	----	24.	15.	----	26.	17.	16.
0.024	O&M Cost (K$/Year)	0.4	----	----	0.5	0.2	----	0.5	0.3	0.2
0.0056	Total Production Cost (cents/1,000 gal)	140.	----	----	160.	94.	----	170.	110.	100.
101-500	Total Capital Cost (K$)	39.	----	----	44.	26.	----	48.	31.	28.
0.087	O&M Cost (K$/Year)	1.1	----	----	1.3	0.6	----	1.4	0.8	0.7
0.024	Total Production Cost (cents/1,000 gal)	66.	----	----	73.	42.	----	81.	51.	46.
501-1,000	Total Capital Cost (K$)	64.	----	----	73.	40.	----	82.	48.	44.
0.27	O&M Cost (K$/Year)	2.4	----	----	2.8	1.3	----	3.1	1.7	1.5
0.086	Total Production Cost (cents/1,000 gal)	32.	----	----	36.	19.	----	41.	23.	21.
1,001-3,000	Total Capital Cost (K$)	100.	----	----	120.	60.	----	130.	75.	67.
0.65	O&M Cost (K$/Year)	5.1	----	----	5.9	2.8	----	6.6	3.5	3.1
0.23	Total Production Cost (cents/1,000 gal)	20.	----	----	24.	12.	----	27.	15.	13.
3,001-10,000	Total Capital Cost (K$)	200.	----	----	230.	110.	----	260.	140.	120.
1.8	O&M Cost (K$/Year)	13.	----	----	15.	7.3	----	17.	9.2	8.1
0.70	Total Production Cost (cents/1,000 gal)	14.	----	----	17.	7.8	----	19.	9.7	8.7
10,001-25,000	Total Capital Cost (K$)	400.	----	----	480.	210.	----	550.	280.	240.
4.8	O&M Cost (K$/Year)	35.	----	----	41.	20.	----	45.	25.	22.
2.1	Total Production Cost (cents/1,000 gal)	11.	----	----	13.	5.9	----	14.	7.5	6.6
25,001-50,000	Total Capital Cost (K$)	800.	----	----	960.	420.	----	1100.	550.	480.
11.	O&M Cost (K$/Year)	83.	----	----	95.	48.	----	110.	58.	52.
5.0	Total Production Cost (cents/1,000 gal)	9.7	----	----	11.	5.3	----	13.	6.7	5.9
50,001-75,000	Total Capital Cost (K$)	1300.	----	----	1500.	650.	----	1800.	860.	750.
18.	O&M Cost (K$/Year)	140.	----	----	160.	82.	----	180.	100.	89.
8.8	Total Production Cost (cents/1,000 gal)	9.1	----	----	11.	4.9	----	12.	6.2	5.5
75,001-100,000	Total Capital Cost (K$)	1800.	----	----	2200.	910.	----	2500.	1200.	1000.
26.	O&M Cost (K$/Year)	210.	----	----	240.	120.	----	270.	150.	130.
13.	Total Production Cost (cents/1,000 gal)	8.8	----	----	10.	4.8	----	12.	6.1	5.3
100,001-500,000	Total Capital Cost (K$)	3400.	----	----	4100.	1700.	----	4800.	2200.	1900.
51.	O&M Cost (K$/Year)	430.	----	----	490.	250.	----	540.	300.	270.
27.	Total Production Cost (cents/1,000 gal)	8.4	----	----	9.8	4.5	----	11.	5.7	5.0
00,001-1,000,000	Total Capital Cost (K$)	13000.	----	----	16000.	5800.	----	18000.	8200.	6900.
210.	O&M Cost (K$/Year)	1900.	----	----	2200.	1200.	----	2400.	1400.	1300.
120.	Total Production Cost (cents/1,000 gal)	7.8	----	----	9.1	4.2	----	10.	5.4	4.7
>1,000,000	Total Capital Cost (K$)	26000.	----	----	31000.	11000.	----	37000.	16000.	13000.
430.	O&M Cost (K$/Year)	4300.	----	----	4900.	2700.	----	5400.	3200.	2900.
270.	Total Production Cost (cents/1,000 gal)	7.4	----	----	8.7	4.1	----	9.9	5.2	4.6

TABLE 7 - 11

Estimated Cost for Removing Dibromochloropropane Using Packed Column Aeration - March 1989

System Size Category Population Range Design Flow (MGD) Average Daily Flow (MGD)		Influent								
		2.0 ug/L			5.0 ug/L			20. ug/L		
		Effluent (ug/L)			Effluent (ug/L)			Effluent (ug/L)		
		0.10	0.20	1.0	0.10	0.20	1.0	0.10	0.20	1.0
	Percent Removed	95.	90.	50.	78.	96.	80.	99.5	99.	95.
25-100	Total Capital Cost (K$)	46.	40.	24.	55.	48.	33.	67.	61.	46.
0.024	O&M Cost (K$/Year)	1.4	1.2	0.6	1.7	1.5	0.9	2.2	2.0	1.4
0.0056	Total Production Cost (cents/1,000 gal)	330.	290. 325 325	160. 300	400.	350.	230.	490.	450.	330.
101-500	Total Capital Cost (K$)	94.	79.	42.	110.	99.	63.	140.	130.	94.
0.087	O&M Cost (K$/Year)	3.9	3.2	1.5	4.7	4.1	2.5	5.9	5.3	3.9
0.024	Total Production Cost (cents/1,000 gal)	170.	140.	73.	210.	180.	110.	260.	230.	170.
501-1,000	Total Capital Cost (K$)	190.	160.	73.	240.	210.	120.	310.	270.	190.
0.27	O&M Cost (K$/Year)	9.9	8.0	3.6	12.	10.	6.2	15.	14.	9.9
0.086	Total Production Cost (cents/1,000 gal)	100.	85.	39.	130.	110.	65.	160.	150.	100.
1,001-3,000	Total Capital Cost (K$)	370.	300.	130.	460.	390.	220.	600.	520.	370.
0.65	O&M Cost (K$/Year)	22.	18.	8.3	27.	23.	14.	35.	31.	22.
0.23	Total Production Cost (cents/1,000 gal)	78.	63.	28.	97.	83.	43.	130.	110.	78.
3,001-10,000	Total Capital Cost (K$)	850.	670.	260.	1100.	910.	490.	1400.	1300.	850.
1.8	O&M Cost (K$/Year)	62.	50.	23.	76.	65.	37.	97.	87.	62.
0.70	Total Production Cost (cents/1,000 gal)	63.	50.	21.	80.	67.	37.	100.	92.	63.
10,001-25,000	Total Capital Cost (K$)	2200.	1700.	610.	2800.	2300.	1200.	3700.	3300.	2200.
4.8	O&M Cost (K$/Year)	170.	140.	65.	210.	180.	110.	270.	240.	170.
2.1	Total Production Cost (cents/1,000 gal)	56.	~~44.~~ 60	18.	70.	59.	32.	92.	81.	56.
25,001-50,000	Total Capital Cost (K$)	4800.	3800.	1300.	6200.	5200.	2700.	8300.	7300.	4800.
11.	O&M Cost (K$/Year)	390.	320.	150.	480.	420.	240.	620.	550.	390.
5.0	Total Production Cost (cents/1,000 gal)	53.	42.	17.	67.	56.	31.	87.	77.	53.
50,001-75,000	Total Capital Cost (K$)	7900.	6100.	2100.	10000.	8400.	4400.	14000.	12000.	7900.
18.	O&M Cost (K$/Year)	660.	540.	260.	820.	700.	410.	1000.	930.	660.
8.8	Total Production Cost (cents/1,000 gal)	49.	39.	16.	62.	53.	29.	82.	72.	49.
75,001-100,000	Total Capital Cost (K$)	11000.	8800.	3000.	15000.	12000.	6200.	19000.	17000.	11000.
26.	O&M Cost (K$/Year)	960.	790.	380.	1200.	1000.	600.	1500.	1300.	960.
13.	Total Production Cost (cents/1,000 gal)	48.	38.	15.	61.	51.	28.	80.	70.	48.
100,001-500,000	Total Capital Cost (K$)	22000.	17000.	5700.	28000.	23000.	12000.	38000.	33000.	22000.
51.	O&M Cost (K$/Year)	1900.	1600.	790.	2400.	2000.	1200.	3000.	2700.	1900.
27.	Total Production Cost (cents/1,000 gal)	46.	36.	15.	58.	48.	27.	75.	66.	46.
500,001-1,000,000	Total Capital Cost (K$)	87000.	67000.	22000.	110000.	93000.	47000.	150000.	130000.	87000.
210.	O&M Cost (K$/Year)	8200.	6800.	3500.	10000.	8700.	5300.	12000.	11000.	8200.
120.	Total Production Cost (cents/1,000 gal)	42.	34.	14.	53.	45.	25.	69.	61.	42.
1,000,000	Total Capital Cost (K$)	180000.	140000.	44000.	220000.	190000.	95000.	310000.	270000.	180000.
[illegible]	O&M Cost (K$/Year)	18000.	15000.	7300.	22000.	19000.	12000.	27000.	24000.	18000.
[illegible]	Total Production Cost (cents/1,000 gal)	[illegible]	[illegible]	13.	49.	42.	[illegible]	[illegible]	57.	39.

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TABLE 7 - 12

Estimated Cost for Removing Ethylene Dibromide (EDB) Using Packed Column Aeration - March 1989

System Size Category ulation Range ign Flow (MGD) verage Daily Flow (MGD)		Influent								
		0.50 ug/L			10. ug/L			50. ug/L		
		Effluent (ug/L)			Effluent (ug/L)			Effluent (ug/L)		
		0.010	0.050	1.0	0.010	0.050	1.0	0.010	0.050	1.0
	Percent Removed	98.	90.		99.9	99.5	90.	99.98	99.9	98.
25-100	Total Capital Cost (K$)	39.	30.	----	56.	47.	30.	64.	56.	39.
0.024	O&M Cost (K$/Year)	1.1	0.8	----	1.6	1.3	0.8	1.8	1.6	1.1
0.0056	Total Production Cost (cents/1,000 gal)	280.	210.	----	400.	330.	210.	460.	400.	280.
101-500	Total Capital Cost (K$)	75.	55.	----	110.	92.	55.	130.	110.	75.
0.087	O&M Cost (K$/Year)	2.7	1.9	----	3.9	3.3	1.9	4.7	3.9	2.7
0.024	Total Production Cost (cents/1,000 gal)	130.	96.	----	190.	160.	96.	230.	190.	130.
501-1,000	Total Capital Cost (K$)	140.	100.	----	220.	180.	100.	260.	220.	140.
0.27	O&M Cost (K$/Year)	6.5	4.5	----	9.9	8.1	4.5	12.	9.9	6.5
0.086	Total Production Cost (cents/1,000 gal)	75.	52.	----	110.	93.	52.	140.	110.	75.
1,001-3,000	Total Capital Cost (K$)	260.	180.	----	410.	330.	180.	490.	410.	260.
0.65	O&M Cost (K$/Year)	14.	9.8	----	22.	18.	9.8	25.	22.	14.
0.23	Total Production Cost (cents/1,000 gal)	53.	36.	----	83.	67.	36.	99.	83.	53.
3,001-10,000	Total Capital Cost (K$)	570.	370.	----	920.	730.	370.	1100.	920.	570.
1.8	O&M Cost (K$/Year)	37.	26.	----	56.	46.	26.	66.	56.	37.
0.70	Total Production Cost (cents/1,000 gal)	40.	27.	----	64.	51.	27.	76.	64.	40.
10,001-25,000	Total Capital Cost (K$)	1300.	850.	----	2200.	1800.	850.	2700.	2200.	1300.
4.8	O&M Cost (K$/Year)	100.	72.	----	160.	130.	72.	190.	160.	100.
2.1	Total Production Cost (cents/1,000 gal)	34.	23.	----	55.	44.	23.	66.	55.	34.
25,001-50,000	Total Capital Cost (K$)	3000.	1900.	----	5000.	3900.	1900.	6000.	5000.	3000.
11.	O&M Cost (K$/Year)	240.	170.	----	370.	300.	170.	430.	370.	240.
5.0	Total Production Cost (cents/1,000 gal)	32.	21.	----	52.	42.	21.	62.	52.	32.
50,001-75,000	Total Capital Cost (K$)	4800.	3000.	----	8000.	6300.	3000.	9700.	8000.	4800.
18.	O&M Cost (K$/Year)	410.	280.	----	620.	510.	280.	720.	620.	410.
8.8	Total Production Cost (cents/1,000 gal)	30.	20.	----	48.	39.	20.	58.	48.	30.
75,001-100,000	Total Capital Cost (K$)	6900.	4300.	----	12000.	9000.	4300.	14000.	12000.	6900.
26.	O&M Cost (K$/Year)	590.	410.	----	890.	730.	410.	1000.	890.	590.
13.	Total Production Cost (cents/1,000 gal)	29.	19.	----	47.	38.	19.	57.	47.	29.
00,001-500,000	Total Capital Cost (K$)	13000.	8200.	----	22000.	17000.	8200.	27000.	22000.	13000.
51.	O&M Cost (K$/Year)	1200.	840.	----	1800.	1500.	840.	2100.	1800.	1200.
27.	Total Production Cost (cents/1,000 gal)	28.	18.	----	45.	36.	18.	53.	45.	28.
00,001-1,000,000	Total Capital Cost (K$)	52000.	32000.	----	88000.	69000.	32000.	110000.	88000.	52000.
210.	O&M Cost (K$/Year)	5100.	3600.	----	7600.	6300.	3600.	8900.	7600.	5100.
120.	Total Production Cost (cents/1,000 gal)	26.	17.	----	41.	33.	17.	49.	41.	26.
>1,000,000	Total Capital Cost (K$)	110000.	65000.	----	180000.	140000.	65000.	220000.	180000.	110000.
430.	O&M Cost (K$/Year)	11000.	8000.	----	16000.	14000.	8000.	19000.	16000.	11000.
270.	Total Production Cost (cents/1,000 gal)	24.	15.	----	38.	33.	15.	45.	38.	24.

TABLE 7 - 13

Estimated Cost for Removing Ethylbenzene Using Packed Column Aeration - March 1989

ystem Size Category ulation Range ign Flow (MGD) verage Daily Flow (MGD)		Influent								
		100. ug/L			700. ug/L			1000. ug/L		
		Effluent (ug/L)			Effluent (ug/L)			Effluent (ug/L)		
		50.	700.	800.	50.	700.	800.	50.	700.	800.
	Percent Removed	50.			92.9			95.	30.	20.
25-100	Total Capital Cost (K$)	15.	----	----	21.	----	----	22.	14.	14.
0.024	O&M Cost (K$/Year)	0.2	----	----	0.4	----	----	0.4	0.2	0.2
0.0056	Total Production Cost (cents/1,000 gal)	99.	----	----	140.	----	----	150.	93.	91.
101-500	Total Capital Cost (K$)	28.	----	----	40.	----	----	43.	26.	25.
0.087	O&M Cost (K$/Year)	0.7	----	----	1.0	----	----	1.1	0.6	0.6
0.024	Total Production Cost (cents/1,000 gal)	45.	----	----	66.	----	----	70.	42.	41.
501-1,000	Total Capital Cost (K$)	43.	----	----	65.	----	----	69.	40.	39.
0.27	O&M Cost (K$/Year)	1.4	----	----	2.3	----	----	2.4	1.3	1.3
0.086	Total Production Cost (cents/1,000 gal)	21.	----	----	32.	----	----	34.	19.	18.
1,001-3,000	Total Capital Cost (K$)	66.	----	----	100.	----	----	110.	59.	57.
0.65	O&M Cost (K$/Year)	3.0	----	----	4.8	----	----	5.1	2.8	2.7
0.23	Total Production Cost (cents/1,000 gal)	13.	----	----	20.	----	----	22.	12.	11.
3,001-10,000	Total Capital Cost (K$)	120.	----	----	200.	----	----	210.	110.	100.
1.8	O&M Cost (K$/Year)	7.9	----	----	12.	----	----	13.	7.3	7.1
0.70	Total Production Cost (cents/1,000 gal)	8.5	----	----	14.	----	----	15.	7.7	7.4
10,001-25,000	Total Capital Cost (K$)	240.	----	----	400.	----	----	430.	210.	220.
4.8	O&M Cost (K$/Year)	22.	----	----	33.	----	----	35.	20.	20.
2.1	Total Production Cost (cents/1,000 gal)	6.5	----	----	10.	----	----	11.	5.9	5.7
25,001-50,000	Total Capital Cost (K$)	460.	----	----	800.	----	----	860.	410.	400.
11.	O&M Cost (K$/Year)	51.	----	----	76.	----	----	81.	47.	46.
5.0	Total Production Cost (cents/1,000 gal)	5.8	----	----	9.3	----	----	9.9	5.3	5.1
50,001-75,000	Total Capital Cost (K$)	720.	----	----	1300.	----	----	1400.	650.	620.
18.	O&M Cost (K$/Year)	87.	----	----	130.	----	----	140.	82.	79.
8.8	Total Production Cost (cents/1,000 gal)	5.4	----	----	8.7	----	----	9.3	4.9	4.7
75,001-100,000	Total Capital Cost (K$)	1000.	----	----	1800.	----	----	1900.	900.	860.
26.	O&M Cost (K$/Year)	130.	----	----	190.	----	----	200.	120.	120.
13.	Total Production Cost (cents/1,000 gal)	5.2	----	----	8.4	----	----	9.0	4.7	4.6
00,001-500,000	Total Capital Cost (K$)	1900.	----	----	3300.	----	----	3600.	1600.	1600.
51.	O&M Cost (K$/Year)	260.	----	----	390.	----	----	420.	250.	240.
27.	Total Production Cost (cents/1,000 gal)	4.9	----	----	7.9	----	----	8.5	4.5	4.3
0,001-1,000,000	Total Capital Cost (K$)	6700.	----	----	12000.	----	----	13000.	5800.	5500.
210.	O&M Cost (K$/Year)	1200.	----	----	1800.	----	----	1900.	1200.	1100.
120.	Total Production Cost (cents/1,000 gal)	4.6	----	----	7.4	----	----	7.9	4.2	4.1
1,000,000	Total Capital Cost (K$)	13000.	----	----	24000.	----	----	27000.	11000.	11000.
470.	O&M Cost (K$/Year)	2300.	----	----	4100.	----	----	4700.	2300.	2300.
270.	Total Production Cost (cents/1,000 gal)	4.5	----	----	7.0	----	----	7.5	4.1	4.0

TABLE 7 - 14

Estimated Cost for Removing m-Xylene Using Packed Column Aeration - March 1989

System Size Category pulation Range sign Flow (MGD) Average Daily Flow (MGD)		Influent 10000. ug/L Effluent (ug/L) 1000.	12000.	15000.	Influent 20000. ug/L Effluent (ug/L) 1000.	12000.	15000.	Influent 50000. ug/L Effluent (ug/L) 1000.	12000.	15000.
	Percent Removed	90.			95.	40.	25.	98.	76.	70.
25-100	Total Capital Cost (K$)	21.	----	----	23.	15.	14.	26.	18.	17.
0.024	O&M Cost (K$/Year)	0.4	----	----	0.4	0.2	0.2	0.5	0.3	0.3
0.0056	Total Production Cost (cents/1,000 gal)	140.	----	----	150.	97.	92.	170.	120.	110.
101-500	Total Capital Cost (K$)	39.	----	----	43.	27.	26.	49.	33.	32.
0.087	O&M Cost (K$/Year)	1.1	----	----	1.2	0.6	0.6	1.4	0.8	0.8
0.024	Total Production Cost (cents/1,000 gal)	64.	----	----	72.	43.	41.	82.	54.	51.
501-1,000	Total Capital Cost (K$)	63.	----	----	71.	42.	39.	83.	53.	50.
0.27	O&M Cost (K$/Year)	2.2	----	----	2.6	1.4	1.3	3.1	1.8	1.7
0.086	Total Production Cost (cents/1,000 gal)	31.	----	----	35.	20.	19.	41.	25.	24.
1,001-3,000	Total Capital Cost (K$)	100.	----	----	120.	63.	58.	130.	82.	77.
0.65	O&M Cost (K$/Year)	4.7	----	----	5.5	2.9	2.7	6.5	3.8	3.5
0.23	Total Production Cost (cents/1,000 gal)	20.	----	----	23.	12.	11.	27.	16.	15.
3,001-10,000	Total Capital Cost (K$)	190.	----	----	220.	110.	100.	260.	150.	140.
1.9	O&M Cost (K$/Year)	12.	----	----	14.	7.6	7.2	17.	9.7	9.1
0.70	Total Production Cost (cents/1,000 gal)	13.	----	----	15.	8.2	7.6	18.	11.	10.
10,001-25,000	Total Capital Cost (K$)	390.	----	----	450.	220.	210.	530.	310.	290.
4.8	O&M Cost (K$/Year)	33.	----	----	38.	21.	20.	44.	27.	25.
2.1	Total Production Cost (cents/1,000 gal)	10.	----	----	12.	6.2	5.8	14.	8.2	7.7
25,001-50,000	Total Capital Cost (K$)	770.	----	----	900.	440.	410.	1100.	610.	570.
11.	O&M Cost (K$/Year)	75.	----	----	87.	49.	47.	100.	61.	58.
5.0	Total Production Cost (cents/1,000 gal)	9.1	----	----	10.	5.5	5.2	12.	7.2	6.8
50,001-75,000	Total Capital Cost (K$)	1200.	----	----	1400.	690.	630.	1700.	960.	890.
18.	O&M Cost (K$/Year)	130.	----	----	150.	84.	81.	170.	100.	99.
8.8	Total Production Cost (cents/1,000 gal)	8.5	----	----	9.8	5.1	4.8	12.	6.8	6.3
75,001-100,000	Total Capital Cost (K$)	1700.	----	----	2000.	960.	880.	2400.	1300.	1200.
26.	O&M Cost (K$/Year)	190.	----	----	220.	120.	120.	260.	150.	140.
13.	Total Production Cost (cents/1,000 gal)	8.2	----	----	9.6	5.0	4.7	11.	6.6	6.1
100,001-500,000	Total Capital Cost (K$)	3200.	----	----	3800.	1800.	1600.	4500.	2500.	2300.
51.	O&M Cost (K$/Year)	390.	----	----	450.	260.	250.	520.	320.	300.
27.	Total Production Cost (cents/1,000 gal)	7.8	----	----	9.0	4.7	4.4	11.	6.2	5.8
500,001-1,000,000	Total Capital Cost (K$)	12000.	----	----	14000.	6300.	5700.	17000.	9100.	8400.
210.	O&M Cost (K$/Year)	1800.	----	----	2000.	1200.	1200.	2400.	1500.	1400.
120.	Total Production Cost (cents/1,000 gal)	7.2	----	----	8.4	4.4	4.2	10.	5.8	5.4
>1,000,000	Total Capital Cost (K$)	24000.	----	----	28000.	12000.	11000.	34000.	18000.	16000.
430.	O&M Cost (K$/Year)	4100.	----	----	4600.	2800.	2700.	5300.	3400.	3200.
270.	Total Production Cost (cents/1,000 gal)	6.9	----	----	8.0	4.3	4.0	9.4	5.6	5.2

TABLE 7 - 15

Estimated Cost for Removing o-Dichlorobenzene Using Packed Column Aeration - March 1989

System Size Category pulation Range sign Flow (MGD) Average Daily Flow (MGD)		Influent 100. ug/L			Influent 700. ug/L			Influent 1000. ug/L		
		Effluent (ug/L)			Effluent (ug/L)			Effluent (ug/L)		
		50.	600.	800.	50.	600.	800.	50.	600.	800.
	Percent Removed	50.			92.9	14.		95.	40.	20.
25-100	Total Capital Cost (K$)	17.	----	----	28.	15.	----	30.	16.	15.
0.024	O&M Cost (K$/Year)	0.3	----	----	0.6	0.2	----	0.7	0.3	0.2
0.0056	Total Production Cost (cents/1,000 gal)	110.	----	----	190.	95.	----	210.	100.	97.
101-500	Total Capital Cost (K$)	31.	----	----	51.	27.	----	54.	29.	27.
0.087	O&M Cost (K$/Year)	0.9	----	----	1.6	0.7	----	1.7	0.8	0.7
0.024	Total Production Cost (cents/1,000 gal)	52.	----	----	86.	43.	----	92.	48.	44.
501-1,000	Total Capital Cost (K$)	48.	----	----	88.	39.	----	96.	45.	40.
0.27	O&M Cost (K$/Year)	1.8	----	----	3.6	1.4	----	3.9	1.6	1.4
0.086	Total Production Cost (cents/1,000 gal)	24.	----	----	45.	19.	----	48.	22.	20.
1,001-3,000	Total Capital Cost (K$)	75.	----	----	150.	59.	----	160.	69.	60.
0.65	O&M Cost (K$/Year)	3.8	----	----	7.7	3.0	----	8.4	3.5	3.1
0.23	Total Production Cost (cents/1,000 gal)	15.	----	----	30.	12.	----	33.	14.	12.
3,001-10,000	Total Capital Cost (K$)	140.	----	----	300.	110.	----	330.	130.	110.
1.8	O&M Cost (K$/Year)	10.	----	----	20.	8.2	----	21.	9.4	8.4
0.70	Total Production Cost (cents/1,000 gal)	10.	----	----	22.	8.1	----	24.	9.4	8.3
10,001-25,000	Total Capital Cost (K$)	280.	----	----	650.	220.	----	710.	260.	220.
4.8	O&M Cost (K$/Year)	28.	----	----	54.	23.	----	59.	26.	23.
2.1	Total Production Cost (cents/1,000 gal)	8.0	----	----	17.	6.3	----	18.	7.3	6.5
25,001-50,000	Total Capital Cost (K$)	560.	----	----	1400.	430.	----	1500.	510.	440.
11.	O&M Cost (K$/Year)	65.	----	----	130.	53.	----	140.	61.	55.
5.0	Total Production Cost (cents/1,000 gal)	7.2	----	----	16.	5.7	----	17.	6.6	5.9
50,001-75,000	Total Capital Cost (K$)	880.	----	----	2200.	670.	----	2500.	800.	690.
18.	O&M Cost (K$/Year)	110.	----	----	210.	92.	----	230.	100.	94.
8.8	Total Production Cost (cents/1,000 gal)	6.7	----	----	15.	5.3	----	16.	6.2	5.5
75,001-100,000	Total Capital Cost (K$)	1200.	----	----	3200.	940.	----	3500.	1100.	970.
26.	O&M Cost (K$/Year)	160.	----	----	310.	140.	----	340.	150.	140.
13.	Total Production Cost (cents/1,000 gal)	6.5	----	----	14.	5.2	----	16.	6.0	5.3
00,001-500,000	Total Capital Cost (K$)	2300.	----	----	6000.	1700.	----	6700.	2100.	1800.
51.	O&M Cost (K$/Year)	340.	----	----	640.	280.	----	690.	320.	290.
27.	Total Production Cost (cents/1,000 gal)	6.2	----	----	14.	4.9	----	15.	5.7	5.0
00,001-1,000,000	Total Capital Cost (K$)	8500.	----	----	23000.	6200.	----	26000.	7500.	6400.
210.	O&M Cost (K$/Year)	1600.	----	----	2300.	1300.	----	3000.	1500.	1300.
120.	Total Production Cost (cents/1,000 gal)	5.8	----	----	13.	4.6	----	14.	5.4	4.9
>1,000,000	Total Capital Cost (K$)	17000.	----	----	47000.	12000.	----	52000.	15000.	12000.
470.	O&M Cost (K$/Year)	3600.	----	----	6200.	3000.	----	6700.	3400.	3100.
270.	Total Production Cost (cents/1,000 gal)	5.6	----	----	12.	4.5	----	13.	5.2	4.6

TABLE 7 - 16

Estimated Cost for Removing o-Xylene Using Packed Column Aeration - March 1989

System Size Category pulation Range sign Flow (MGD) Average Daily Flow (MGD)		Influent								
		10000. ug/L			20000. ug/L			50000. ug/L		
		Effluent (ug/L)			Effluent (ug/L)			Effluent (ug/L)		
		1000.	12000.	15000.	1000.	12000.	15000.	1000.	12000.	15000.
	Percent Removed	90.			95.	40.	25.	98.	76.	70.
25-100	Total Capital Cost (K$)	21.	----	----	23.	15.	14.	26.	18.	17.
0.024	O&M Cost (K$/Year)	0.4	----	----	0.4	0.2	0.2	0.5	0.3	0.3
0.0056	Total Production Cost (cents/1,000 gal)	140.	----	----	150.	97.	93.	180.	120.	110.
101-500	Total Capital Cost (K$)	40.	----	----	44.	27.	26.	50.	34.	32.
0.087	O&M Cost (K$/Year)	1.1	----	----	1.2	0.7	0.6	1.4	0.8	0.8
0.024	Total Production Cost (cents/1,000 gal)	65.	----	----	73.	43.	41.	83.	55.	52.
501-1,000	Total Capital Cost (K$)	64.	----	----	72.	42.	39.	84.	53.	50.
0.27	O&M Cost (K$/Year)	2.3	----	----	2.7	1.4	1.3	3.1	1.8	1.7
0.086	Total Production Cost (cents/1,000 gal)	31.	----	----	36.	20.	19.	42.	26.	24.
1,001-3,000	Total Capital Cost (K$)	100.	----	----	120.	63.	58.	140.	83.	78.
0.65	O&M Cost (K$/Year)	4.8	----	----	5.6	2.9	2.7	6.6	3.8	3.6
0.23	Total Production Cost (cents/1,000 gal)	20.	----	----	23.	12.	11.	27.	16.	15.
3,001-10,000	Total Capital Cost (K$)	190.	----	----	220.	110.	100.	270.	150.	140.
1.8	O&M Cost (K$/Year)	13.	----	----	14.	7.6	7.2	17.	9.9	9.3
0.70	Total Production Cost (cents/1,000 gal)	14.	----	----	16.	8.2	7.6	19.	11.	10.
10,001-25,000	Total Capital Cost (K$)	390.	----	----	460.	230.	210.	550.	310.	290.
4.8	O&M Cost (K$/Year)	34.	----	----	39.	21.	20.	45.	27.	25.
2.1	Total Production Cost (cents/1,000 gal)	10.	----	----	12.	6.2	5.8	14.	8.3	7.8
25,001-50,000	Total Capital Cost (K$)	780.	----	----	920.	440.	410.	1100.	620.	570.
11.	O&M Cost (K$/Year)	77.	----	----	89.	49.	47.	110.	62.	58.
5.0	Total Production Cost (cents/1,000 gal)	9.3	----	----	11.	5.5	5.2	13.	7.4	6.9
50,001-75,000	Total Capital Cost (K$)	1200.	----	----	1500.	690.	630.	1700.	970.	900.
18.	O&M Cost (K$/Year)	130.	----	----	150.	85.	81.	180.	110.	100.
8.8	Total Production Cost (cents/1,000 gal)	8.7	----	----	10.	5.2	4.9	12.	6.9	6.4
75,001-100,000	Total Capital Cost (K$)	1800.	----	----	2100.	970.	890.	2500.	1400.	1300.
26.	O&M Cost (K$/Year)	190.	----	----	220.	120.	120.	270.	160.	150.
13.	Total Production Cost (cents/1,000 gal)	8.4	----	----	9.8	5.0	4.7	12.	6.7	6.2
100,001-500,000	Total Capital Cost (K$)	3300.	----	----	3900.	1800.	1600.	4700.	2500.	2400.
51.	O&M Cost (K$/Year)	400.	----	----	460.	260.	250.	540.	320.	300.
27.	Total Production Cost (cents/1,000 gal)	7.9	----	----	9.3	4.7	4.4	11.	6.3	5.9
500,001-1,000,000	Total Capital Cost (K$)	12000.	----	----	15000.	6300.	5700.	18000.	9300.	8600.
210.	O&M Cost (K$/Year)	1800.	----	----	2100.	1200.	1200.	2400.	1500.	1400.
120.	Total Production Cost (cents/1,000 gal)	7.4	----	----	8.6	4.4	4.2	10.	5.9	5.5
>1,000,000	Total Capital Cost (K$)	24000.	----	----	29000.	12000.	11000.	36000.	18000.	17000.
470.	O&M Cost (K$/Year)	4200.	----	----	4700.	2800.	2700.	5400.	3400.	[illegible]
270.	Total Production Cost (cents/1,000 gal)	[illegible]	----	----	8.2	4.7	4.1	[illegible]	[illegible]	[illegible]

TABLE 7 - 17

Estimated Cost for Removing p-Xylene Using Packed Column Aeration - March 1989

System Size Category ulation Range ign Flow (MGD) Average Daily Flow (MGD)		Influent								
		10000. ug/L			20000. ug/L			50000. ug/L		
		Effluent (ug/L)			Effluent (ug/L)			Effluent (ug/L)		
		1000.	12000.	15000.	1000.	12000.	15000.	1000.	12000.	15000.
	Percent Removed	90.			95.	40.	25.	98.	76.	70.
25-100	Total Capital Cost (K$)	21.	----	----	23.	15.	14.	25.	18.	17.
0.024	O&M Cost (K$/Year)	0.4	----	----	0.4	0.2	0.2	0.5	0.3	0.3
0.0056	Total Production Cost (cents/1,000 gal)	140.	----	----	150.	96.	92.	170.	120.	110.
101-500	Total Capital Cost (K$)	39.	----	----	43.	27.	26.	49.	33.	31.
0.087	O&M Cost (K$/Year)	1.0	----	----	1.2	0.6	0.6	1.4	0.8	0.8
0.024	Total Production Cost (cents/1,000 gal)	64.	----	----	71.	43.	41.	81.	53.	51.
501-1,000	Total Capital Cost (K$)	62.	----	----	71.	42.	39.	82.	52.	50.
0.27	O&M Cost (K$/Year)	2.2	----	----	2.5	1.4	1.3	3.0	1.8	1.7
0.086	Total Production Cost (cents/1,000 gal)	30.	----	----	35.	20.	19.	40.	25.	24.
1,001-3,000	Total Capital Cost (K$)	99.	----	----	110.	63.	58.	130.	81.	77.
0.65	O&M Cost (K$/Year)	4.6	----	----	5.3	2.9	2.7	6.3	3.7	3.5
0.23	Total Production Cost (cents/1,000 gal)	19.	----	----	22.	12.	11.	26.	16.	15.
3,001-10,000	Total Capital Cost (K$)	190.	----	----	220.	110.	100.	250.	150.	140.
1.8	O&M Cost (K$/Year)	12.	----	----	14.	7.6	7.2	16.	9.6	9.0
0.70	Total Production Cost (cents/1,000 gal)	13.	----	----	15.	8.1	7.6	18.	11.	10.
10,001-25,000	Total Capital Cost (K$)	380.	----	----	440.	220.	210.	520.	300.	280.
4.8	O&M Cost (K$/Year)	32.	----	----	37.	21.	20.	43.	26.	25.
2.1	Total Production Cost (cents/1,000 gal)	10.	----	----	12.	6.2	5.8	14.	8.1	7.6
25,001-50,000	Total Capital Cost (K$)	760.	----	----	880.	440.	410.	1000.	600.	560.
11.	O&M Cost (K$/Year)	73.	----	----	84.	49.	47.	98.	60.	57.
5.0	Total Production Cost (cents/1,000 gal)	8.9	----	----	10.	5.5	5.2	12.	7.2	6.7
50,001-75,000	Total Capital Cost (K$)	1200.	----	----	1400.	680.	630.	1700.	950.	880.
18.	O&M Cost (K$/Year)	130.	----	----	140.	84.	81.	170.	100.	98.
8.8	Total Production Cost (cents/1,000 gal)	8.3	----	----	9.6	5.1	4.8	11.	6.7	6.3
75,001-100,000	Total Capital Cost (K$)	1700.	----	----	2000.	960.	880.	2400.	1300.	1200.
26.	O&M Cost (K$/Year)	180.	----	----	210.	120.	120.	250.	150.	140.
13.	Total Production Cost (cents/1,000 gal)	8.1	----	----	9.3	5.0	4.7	11.	6.5	6.1
100,001-500,000	Total Capital Cost (K$)	3200.	----	----	3700.	1800.	1600.	4400.	2500.	2300.
51.	O&M Cost (K$/Year)	380.	----	----	440.	260.	240.	510.	310.	300.
27.	Total Production Cost (cents/1,000 gal)	7.6	----	----	8.8	4.7	4.4	10.	6.1	5.7
500,001-1,000,000	Total Capital Cost (K$)	12000.	----	----	14000.	6200.	5700.	17000.	9000.	8300.
210.	O&M Cost (K$/Year)	1700.	----	----	2000.	1200.	1200.	2300.	1400.	1400.
120.	Total Production Cost (cents/1,000 gal)	7.1	----	----	8.2	4.4	4.2	9.7	5.7	5.4
>1,000,000	Total Capital Cost (K$)	23000.	----	----	27000.	12000.	11000.	33000.	18000.	16000.
430.	O&M Cost (K$/Year)	4000.	----	----	4500.	2800.	2700.	5200.	3300.	3200.
270.	Total Production Cost (cents/1,000 gal)	6.3	----	----	7.3	4.3	4.0	9.2	5.5	5.2

TABLE 7 - 18

Estimated Cost for Removing Styrene Using Packed Column Aeration - March 1989

ystem Size Category lation Range gn Flow (MGD) verage Daily Flow (MGD)		Influent								
		10. ug/L			50. ug/L			200. ug/L		
		Effluent (ug/L)			Effluent (ug/L)			Effluent (ug/L)		
		2.0	5.0	20.	2.0	5.0	20.	2.0	5.0	20.
	Percent Removed	80.	50.		96.	90.	60.	99.	97.5	90.
25-100	Total Capital Cost (K$)	20.	16.	----	27.	23.	17.	33.	29.	23.
0.024	O&M Cost (K$/Year)	0.4	0.3	----	0.6	0.5	0.3	0.7	0.6	0.5
0.0056	Total Production Cost (cents/1,000 gal)	130.	110.	----	190.	160.	110.	230.	200.	160.
101-500	Total Capital Cost (K$)	38.	30.	----	51.	43.	32.	62.	54.	43.
0.087	O&M Cost (K$/Year)	1.1	0.7	----	1.5	1.3	0.9	1.9	1.6	1.3
0.024	Total Production Cost (cents/1,000 gal)	62.	48.	----	85.	72.	52.	100.	91.	72.
501-1,000	Total Capital Cost (K$)	60.	46.	----	87.	72.	49.	110.	95.	72.
0.27	O&M Cost (K$/Year)	2.3	1.6	----	3.4	2.8	1.8	4.2	3.7	2.8
0.086	Total Production Cost (cents/1,000 gal)	30.	22.	----	43.	36.	24.	54.	47.	36.
1,001-3,000	Total Capital Cost (K$)	96.	71.	----	140.	120.	77.	190.	160.	120.
0.65	O&M Cost (K$/Year)	4.9	3.3	----	7.2	5.9	3.7	9.1	7.9	5.9
0.23	Total Production Cost (cents/1,000 gal)	19.	14.	----	29.	24.	15.	37.	32.	24.
3,001-10,000	Total Capital Cost (K$)	180.	130.	----	290.	230.	140.	370.	320.	230.
1.8	O&M Cost (K$/Year)	13.	8.7	----	18.	15.	9.7	23.	20.	15.
0.70	Total Production Cost (cents/1,000 gal)	13.	9.3	----	20.	17.	10.	26.	22.	17.
10,001-25,000	Total Capital Cost (K$)	380.	260.	----	610.	480.	290.	900.	630.	480.
4.8	O&M Cost (K$/Year)	34.	24.	----	49.	41.	26.	61.	54.	41.
2.1	Total Production Cost (cents/1,000 gal)	10.	7.1	----	16.	13.	7.8	20.	17.	13.
25,001-50,000	Total Capital Cost (K$)	760.	520.	----	1300.	970.	570.	1700.	1400.	970.
11.	O&M Cost (K$/Year)	80.	55.	----	120.	96.	61.	150.	130.	96.
5.0	Total Production Cost (cents/1,000 gal)	9.2	6.3	----	14.	12.	7.0	19.	16.	12.
50,001-75,000	Total Capital Cost (K$)	1200.	810.	----	2000.	1600.	900.	2700.	2200.	1600.
18.	O&M Cost (K$/Year)	140.	95.	----	200.	160.	100.	250.	220.	160.
8.8	Total Production Cost (cents/1,000 gal)	8.6	5.9	----	14.	11.	6.5	18.	15.	11.
75,001-100,000	Total Capital Cost (K$)	1700.	1100.	----	2900.	2200.	1300.	3800.	3200.	2200.
26.	O&M Cost (K$/Year)	200.	140.	----	290.	240.	150.	360.	320.	240.
13.	Total Production Cost (cents/1,000 gal)	8.4	5.7	----	13.	10.	6.4	17.	14.	10.
00,001-500,000	Total Capital Cost (K$)	3200.	2100.	----	5400.	4200.	2300.	7300.	6100.	4200.
51.	O&M Cost (K$/Year)	410.	290.	----	590.	490.	320.	730.	640.	490.
27.	Total Production Cost (cents/1,000 gal)	8.0	5.4	----	13.	9.9	6.0	16.	14.	9.9
0,001-1,000,000	Total Capital Cost (K$)	12000.	7600.	----	21000.	16000.	8500.	29000.	24000.	16000.
210.	O&M Cost (K$/Year)	1900.	1300.	----	2600.	2200.	1500.	3300.	2800.	2200.
120.	Total Production Cost (cents/1,000 gal)	7.4	5.1	----	12.	9.2	5.6	15.	13.	9.2
1,000,000	Total Capital Cost (K$)	24000.	15000.	----	42000.	32000.	17000.	55000.	47000.	32000.
470.	O&M Cost (K$/Year)	4200.	3100.	----	5800.	4900.	3400.	7100.	6300.	4900.
270.	Total Production Cost (cents/1,000 gal)	7.1	4.9	----	11.	8.3	5.4	14.	12.	8.3

TABLE 7 - 19

Estimated Cost for Removing trans-1,2-Dichloroethylene Using Packed Column Aeration - March 1989

System Size Category Population Range Design Flow (MGD) Average Daily Flow (MGD)		Influent 50. ug/L Effluent (ug/L) 5.0	70.	100.	Influent 100. ug/L Effluent (ug/L) 5.0	70.	100.	Influent 500. ug/L Effluent (ug/L) 5.0	70.	100.
	Percent Removed	90.			95.	30.		99.	86.	80.
25-100	Total Capital Cost (K$)	20.	----	----	21.	14.	----	26.	19.	15.
0.024	O&M Cost (K$/Year)	0.3	----	----	0.4	0.2	----	0.5	0.3	0.3
0.0056	Total Production Cost (cents/1,000 gal)	130.	----	----	140.	93.	----	170.	120.	120.
101-500	Total Capital Cost (K$)	37.	----	----	41.	26.	----	49.	35.	33.
0.087	O&M Cost (K$/Year)	0.9	----	----	1.1	0.6	----	1.4	0.9	0.8
0.024	Total Production Cost (cents/1,000 gal)	60.	----	----	67.	42.	----	82.	57.	53.
501-1,000	Total Capital Cost (K$)	59.	----	----	66.	39.	----	83.	56.	52.
0.27	O&M Cost (K$/Year)	2.1	----	----	2.4	1.3	----	3.0	1.9	1.8
0.086	Total Production Cost (cents/1,000 gal)	29.	----	----	32.	19.	----	41.	27.	25.
1,001-3,300	Total Capital Cost (K$)	93.	----	----	110.	59.	----	130.	87.	81.
0.65	O&M Cost (K$/Year)	4.3	----	----	5.0	2.7	----	6.4	4.0	3.7
0.23	Total Production Cost (cents/1,000 gal)	18.	----	----	21.	12.	----	25.	17.	16.
3,301-10,000	Total Capital Cost (K$)	180.	----	----	210.	110.	----	260.	160.	150.
1.8	O&M Cost (K$/Year)	11.	----	----	13.	7.2	----	16.	10.	9.2
0.70	Total Production Cost (cents/1,000 gal)	12.	----	----	14.	7.7	----	18.	12.	11.
10,001-25,000	Total Capital Cost (K$)	360.	----	----	410.	210.	----	530.	330.	310.
4.8	O&M Cost (K$/Year)	30.	----	----	34.	20.	----	44.	28.	26.
2.1	Total Production Cost (cents/1,000 gal)	9.4	----	----	11.	5.3	----	14.	8.7	8.0
25,001-50,000	Total Capital Cost (K$)	710.	----	----	820.	410.	----	1100.	650.	600.
11.	O&M Cost (K$/Year)	70.	----	----	79.	47.	----	100.	65.	60.
5.0	Total Production Cost (cents/1,000 gal)	8.4	----	----	9.6	5.2	----	12.	7.8	7.1
50,001-75,000	Total Capital Cost (K$)	1100.	----	----	1300.	640.	----	1700.	1000.	940.
18.	O&M Cost (K$/Year)	120.	----	----	140.	81.	----	170.	110.	100.
8.8	Total Production Cost (cents/1,000 gal)	7.8	----	----	8.9	4.8	----	12.	7.2	6.7
75,001-100,000	Total Capital Cost (K$)	1600.	----	----	1800.	890.	----	2400.	1500.	1300.
26.	O&M Cost (K$/Year)	170.	----	----	200.	120.	----	250.	160.	150.
13.	Total Production Cost (cents/1,000 gal)	7.6	----	----	8.7	4.7	----	11.	7.0	6.5
100,001-500,000	Total Capital Cost (K$)	2900.	----	----	3400.	1600.	----	4500.	2700.	2500.
51.	O&M Cost (K$/Year)	360.	----	----	410.	250.	----	520.	340.	310.
27.	Total Production Cost (cents/1,000 gal)	7.1	----	----	8.2	4.4	----	11.	6.6	6.1
500,001-1,000,000	Total Capital Cost (K$)	11000.	----	----	13000.	5700.	----	17000.	10000.	9000.
210.	O&M Cost (K$/Year)	1700.	----	----	1900.	1200.	----	2300.	1600.	1400.
120.	Total Production Cost (cents/1,000 gal)	6.7	----	----	7.6	4.2	----	9.9	6.2	5.7
>1,000,000	Total Capital Cost (K$)	[illegible]	----	----	25000.	11000.	----	34000.	21000.	[illegible]
[illegible]	O&M Cost (K$/Year)	[illegible]	----	----	[illegible]	[illegible]	----	[illegible]	[illegible]	[illegible]
[illegible]	Total Production Cost (cents/1,000 gal)	[illegible]	----	----	[illegible]	[illegible]	----	9.4	[illegible]	[illegible]

TABLE 7 - 20

Estimated Cost for Removing Tetrachloroethylene Using Packed Column Aeration - March 1989

System Size Category Population Range Design Flow (MGD) Average Daily Flow (MGD)		Influent 50. ug/L			Influent 100. ug/L			Influent 500. ug/L		
		Effluent (ug/L)			Effluent (ug/L)			Effluent (ug/L)		
		1.0	5.0	50.	1.0	5.0	50.	1.0	5.0	50.
	Percent Removed	98.	90.		99.	95.	50.	99.8	99.	90.
25-100	Total Capital Cost (K$)	24.	19.	----	25.	21.	15.	29.	25.	19.
0.024	O&M Cost (K$/Year)	0.4	0.3	----	0.5	0.4	0.2	0.6	0.5	0.3
0.0056	Total Production Cost (cents/1,000 gal)	160.	130.	----	170.	140.	98.	200.	170.	130.
101-500	Total Capital Cost (K$)	45.	36.	----	49.	40.	27.	57.	49.	36.
0.087	O&M Cost (K$/Year)	1.1	0.9	----	1.2	1.0	0.7	1.5	1.2	0.9
0.024	Total Production Cost (cents/1,000 gal)	73.	58.	----	79.	65.	44.	94.	79.	58.
501-1,000	Total Capital Cost (K$)	74.	59.	----	81.	66.	43.	97.	81.	59.
0.27	O&M Cost (K$/Year)	2.5	2.0	----	2.8	2.2	1.4	3.4	2.8	2.0
0.086	Total Production Cost (cents/1,000 gal)	36.	28.	----	39.	32.	20.	47.	39.	28.
1,001-3,000	Total Capital Cost (K$)	120.	92.	----	130.	100.	64.	160.	130.	92.
0.65	O&M Cost (K$/Year)	5.3	4.1	----	5.8	4.6	3.0	7.0	5.8	4.1
0.23	Total Production Cost (cents/1,000 gal)	23.	18.	----	25.	20.	13.	31.	25.	18.
3,001-10,000	Total Capital Cost (K$)	230.	170.	----	250.	200.	120.	310.	250.	170.
1.8	O&M Cost (K$/Year)	14.	10.	----	15.	12.	7.8	19.	15.	10.
0.70	Total Production Cost (cents/1,000 gal)	16.	12.	----	17.	14.	8.4	21.	17.	12.
10,001-25,000	Total Capital Cost (K$)	460.	350.	----	510.	400.	230.	630.	510.	350.
4.8	O&M Cost (K$/Year)	36.	28.	----	40.	32.	21.	48.	40.	28.
2.1	Total Production Cost (cents/1,000 gal)	12.	9.0	----	13.	10.	6.3	16.	13.	9.0
25,001-50,000	Total Capital Cost (K$)	930.	690.	----	1000.	790.	450.	1300.	1000.	690.
11.	O&M Cost (K$/Year)	83.	66.	----	91.	73.	50.	110.	91.	66.
5.0	Total Production Cost (cents/1,000 gal)	10.	8.0	----	12.	9.1	5.7	14.	12.	8.0
50,001-75,000	Total Capital Cost (K$)	1500.	1100.	----	1600.	1300.	710.	2000.	1600.	1100.
18.	O&M Cost (K$/Year)	140.	110.	----	160.	120.	86.	190.	160.	110.
8.8	Total Production Cost (cents/1,000 gal)	9.8	7.5	----	11.	8.5	5.3	13.	11.	7.5
75,001-100,000	Total Capital Cost (K$)	2100.	1500.	----	2300.	1800.	990.	2800.	2300.	1500.
26.	O&M Cost (K$/Year)	210.	170.	----	230.	180.	130.	270.	230.	170.
13.	Total Production Cost (cents/1,000 gal)	9.5	7.2	----	10.	8.2	5.1	13.	10.	7.2
100,001-500,000	Total Capital Cost (K$)	3900.	2800.	----	4300.	3300.	1800.	5400.	4300.	2800.
51.	O&M Cost (K$/Year)	430.	340.	----	470.	380.	260.	560.	470.	340.
27.	Total Production Cost (cents/1,000 gal)	9.0	6.8	----	9.9	7.7	4.8	12.	9.9	6.8
500,001-1,000,000	Total Capital Cost (K$)	15000.	10000.	----	16000.	12000.	6500.	20000.	16000.	10000.
210.	O&M Cost (K$/Year)	1900.	1600.	----	2100.	1700.	1200.	2500.	2100.	1600.
120.	Total Production Cost (cents/1,000 gal)	8.3	6.4	----	9.2	7.2	4.5	11.	9.2	6.4
>1,000,000	Total Capital Cost (K$)	29000.	20000.	----	32000.	24000.	13000.	40000.	32000.	20000.
520.	O&M Cost (K$/Year)	4300.	3600.	----	4500.	3300.	2500.	5600.	4500.	3600.
270.	Total Production Cost (cents/1,000 gal)	7.9	6.1	----	8.7	6.9	4.4	10.	8.7	6.1

TABLE 7 - 21

Estimated Cost for Removing Toluene Using Packed Column Aeration - March 1989

ystem Size Category ulation Range ign Flow (MGD) verage Daily Flow (MGD)		Influent								
		500. ug/L			3000. ug/L			5000. ug/L		
		Effluent (ug/L)			Effluent (ug/L)			Effluent (ug/L)		
		100.	2000.	3000.	100.	2000.	3000.	100.	2000.	3000.
	Percent Removed	80.			96.7	33.		98.	60.	40.
25-100	Total Capital Cost (K$)	18.	----	----	23.	15.	----	25.	16.	15.
0.024	O&M Cost (K$/Year)	0.3	----	----	0.4	0.2	----	0.5	0.2	0.2
0.0056	Total Production Cost (cents/1,000 gal)	120.	----	----	150.	94.	----	160.	100.	96.
101-500	Total Capital Cost (K$)	33.	----	----	44.	26.	----	47.	29.	27.
0.087	O&M Cost (K$/Year)	0.8	----	----	1.2	0.6	----	1.3	0.7	0.6
0.024	Total Production Cost (cents/1,000 gal)	54.	----	----	73.	42.	----	78.	47.	43.
501-1,000	Total Capital Cost (K$)	53.	----	----	73.	40.	----	78.	46.	41.
0.27	O&M Cost (K$/Year)	1.8	----	----	2.6	1.3	----	2.8	1.5	1.4
0.086	Total Production Cost (cents/1,000 gal)	26.	----	----	35.	19.	----	38.	22.	20.
1,001-3,000	Total Capital Cost (K$)	83.	----	----	120.	60.	----	130.	70.	62.
0.65	O&M Cost (K$/Year)	3.8	----	----	5.5	2.8	----	5.9	3.1	2.9
0.23	Total Production Cost (cents/1,000 gal)	16.	----	----	23.	12.	----	25.	14.	12.
3,001-10,000	Total Capital Cost (K$)	150.	----	----	220.	110.	----	240.	130.	110.
1.8	O&M Cost (K$/Year)	9.7	----	----	14.	7.4	----	15.	8.2	7.5
0.70	Total Production Cost (cents/1,000 gal)	11.	----	----	16.	7.9	----	17.	9.0	8.1
10,001-25,000	Total Capital Cost (K$)	310.	----	----	460.	210.	----	500.	250.	220.
4.8	O&M Cost (K$/Year)	27.	----	----	38.	21.	----	41.	23.	21.
2.1	Total Production Cost (cents/1,000 gal)	8.2	----	----	12.	5.9	----	13.	6.8	6.1
25,001-50,000	Total Capital Cost (K$)	610.	----	----	910.	420.	----	1000.	500.	430.
11.	O&M Cost (K$/Year)	61.	----	----	86.	48.	----	93.	53.	49.
5.0	Total Production Cost (cents/1,000 gal)	7.3	----	----	11.	5.3	----	12.	6.1	5.5
50,001-75,000	Total Capital Cost (K$)	970.	----	----	1400.	650.	----	1600.	770.	620.
18.	O&M Cost (K$/Year)	100.	----	----	150.	82.	----	160.	91.	84.
8.8	Total Production Cost (cents/1,000 gal)	6.8	----	----	9.9	4.9	----	11.	5.7	5.1
75,001-100,000	Total Capital Cost (K$)	1400.	----	----	2000.	910.	----	2200.	1100.	950.
26.	O&M Cost (K$/Year)	150.	----	----	220.	120.	----	230.	130.	120.
13.	Total Production Cost (cents/1,000 gal)	6.6	----	----	9.6	4.8	----	10.	5.5	4.9
00,001-500,000	Total Capital Cost (K$)	2500.	----	----	3800.	1700.	----	4200.	2000.	1700.
51.	O&M Cost (K$/Year)	320.	----	----	440.	250.	----	480.	280.	250.
27.	Total Production Cost (cents/1,000 gal)	6.2	----	----	9.1	4.5	----	9.9	5.2	4.6
0,001-1,000,000	Total Capital Cost (K$)	9200.	----	----	14000.	5900.	----	16000.	7200.	6100.
210.	O&M Cost (K$/Year)	1500.	----	----	2000.	1200.	----	2200.	1300.	1200.
120.	Total Production Cost (cents/1,000 gal)	5.3	----	----	8.4	4.3	----	9.2	4.9	4.4
1,000,000	Total Capital Cost (K$)	18000.	----	----	28000.	11000.	----	31000.	14000.	12000.
430.	O&M Cost (K$/Year)	3400.	----	----	4600.	2700.	----	4900.	3000.	2800.
270.	Total Production Cost (cents/1,000 gal)	[illegible]	----	----	[illegible]	4.1	----	8.7	4.7	4.2

TABLE 7 - 22

Estimated Cost for Removing 1,2-Dichloropropane Using Packed Column Aeration - March 1989

System Size Category Population Range Design Flow (MGD) Average Daily Flow (MGD)		Influent								
		10. ug/L			50. ug/L			100. ug/L		
		Effluent (ug/L)			Effluent (ug/L)			Effluent (ug/L)		
		2.0	5.0	10.	2.0	5.0	10.	2.0	5.0	10.
	Percent Removed	80.	50.		96.	90.	80.	98.	95.	90.
25-100	Total Capital Cost (K$)	21.	16.	----	28.	24.	21.	31.	27.	24.
0.024	O&M Cost (K$/Year)	0.4	0.3	----	0.6	0.5	0.4	0.7	0.6	0.5
0.0056	Total Production Cost (cents/1,000 gal)	140.	110.	----	190.	160.	140.	210.	180.	160.
101-500	Total Capital Cost (K$)	38.	30.	----	51.	44.	38.	57.	49.	44.
0.087	O&M Cost (K$/Year)	1.1	0.8	----	1.5	1.3	1.1	1.7	1.5	1.3
0.024	Total Production Cost (cents/1,000 gal)	63.	49.	----	86.	73.	63.	96.	83.	73.
501-1,000	Total Capital Cost (K$)	61.	46.	----	88.	73.	61.	100.	85.	73.
0.27	O&M Cost (K$/Year)	2.4	1.6	----	3.5	2.9	2.4	4.0	3.3	2.9
0.086	Total Production Cost (cents/1,000 gal)	30.	22.	----	44.	36.	30.	50.	42.	36.
1,001-3,000	Total Capital Cost (K$)	98.	71.	----	150.	120.	98.	170.	140.	120.
0.65	O&M Cost (K$/Year)	5.0	3.4	----	7.4	6.1	5.0	8.4	7.1	6.1
0.23	Total Production Cost (cents/1,000 gal)	20.	14.	----	29.	24.	20.	34.	28.	24.
3,001-10,000	Total Capital Cost (K$)	190.	130.	----	300.	240.	190.	340.	280.	240.
1.9	O&M Cost (K$/Year)	13.	8.9	----	19.	16.	13.	22.	18.	16.
0.70	Total Production Cost (cents/1,000 gal)	14.	9.5	----	21.	17.	14.	24.	20.	17.
10,001-25,000	Total Capital Cost (K$)	390.	260.	----	620.	500.	390.	730.	600.	500.
4.8	O&M Cost (K$/Year)	35.	24.	----	51.	42.	35.	57.	49.	42.
2.1	Total Production Cost (cents/1,000 gal)	11.	7.2	----	16.	13.	11.	19.	15.	13.
25,001-50,000	Total Capital Cost (K$)	790.	520.	----	1300.	1000.	790.	1500.	1200.	1000.
11.	O&M Cost (K$/Year)	82.	57.	----	120.	99.	82.	140.	120.	99.
5.0	Total Production Cost (cents/1,000 gal)	9.6	6.4	----	15.	12.	9.6	17.	14.	12.
50,001-75,000	Total Capital Cost (K$)	1300.	920.	----	2100.	1600.	1300.	2500.	2000.	1600.
18.	O&M Cost (K$/Year)	140.	97.	----	210.	170.	140.	230.	200.	170.
8.8	Total Production Cost (cents/1,000 gal)	9.0	6.0	----	14.	11.	9.0	16.	13.	11.
75,001-100,000	Total Capital Cost (K$)	1800.	1100.	----	3000.	2300.	1800.	3500.	2900.	2300.
26.	O&M Cost (K$/Year)	210.	140.	----	300.	250.	210.	340.	290.	250.
13.	Total Production Cost (cents/1,000 gal)	8.7	5.8	----	14.	11.	8.7	16.	13.	11.
100,001-500,000	Total Capital Cost (K$)	3300.	2100.	----	5700.	4400.	3300.	6700.	5400.	4400.
51.	O&M Cost (K$/Year)	420.	300.	----	610.	510.	420.	690.	590.	510.
27.	Total Production Cost (cents/1,000 gal)	8.3	5.5	----	13.	10.	8.3	15.	12.	10.
500,001-1,000,000	Total Capital Cost (K$)	13000.	7600.	----	22000.	17000.	13000.	26000.	21000.	17000.
210.	O&M Cost (K$/Year)	1900.	1400.	----	2700.	2300.	1900.	3000.	2600.	2300.
120.	Total Production Cost (cents/1,000 gal)	7.7	5.2	----	12.	9.6	7.7	14.	12.	9.6
1,000,000	Total Capital Cost (K$)	25000.	15000.	----	44000.	33000.	25000.	52000.	42000.	33000.
430.	O&M Cost (K$/Year)	4700.	3300.	----	6000.	5100.	4700.	6700.	5800.	5100.
270.	Total Production Cost (cents/1,000 gal)	7.4	5.0	----	11.	9.1	7.4	13.	11.	9.1

TABLE 7 - 23

Estimated Cost for Removing Toxaphene Using Packed Column Aeration - March 1989

System Size Category opulation Range esign Flow (MGD) Average Daily Flow (MGD)		Influent								
		5.0 ug/L			10. ug/L			50. ug/L		
		Effluent (ug/L)			Effluent (ug/L)			Effluent (ug/L)		
		1.0	5.0	10.	1.0	5.0	10.	1.0	5.0	10.
	Percent Removed	80.			90.	50.		98.	90.	80.
25-100	Total Capital Cost (K$)	20.	----	----	23.	16.	----	29.	23.	20.
0.024	O&M Cost (K$/Year)	0.3	----	----	0.4	0.2	----	0.6	0.4	0.3
0.0056	Total Production Cost (cents/1,000 gal)	130.	----	----	150.	100.	----	200.	150.	130.
101-500	Total Capital Cost (K$)	38.	----	----	43.	29.	----	57.	43.	38.
0.087	O&M Cost (K$/Year)	0.9	----	----	1.2	0.7	----	1.6	1.2	0.9
0.024	Total Production Cost (cents/1,000 gal)	61.	----	----	71.	47.	----	94.	71.	61.
501-1,000	Total Capital Cost (K$)	60.	----	----	71.	46.	----	96.	71.	60.
0.27	O&M Cost (K$/Year)	2.1	----	----	2.6	1.5	----	3.6	2.6	2.1
0.086	Total Production Cost (cents/1,000 gal)	29.	----	----	35.	22.	----	47.	35.	29.
1,001-3,000	Total Capital Cost (K$)	95.	----	----	110.	70.	----	160.	110.	95.
0.65	O&M Cost (K$/Year)	4.4	----	----	5.3	3.2	----	7.5	5.3	4.4
0.23	Total Production Cost (cents/1,000 gal)	19.	----	----	22.	14.	----	31.	22.	19.
3,001-10,000	Total Capital Cost (K$)	130.	----	----	220.	170.	----	310.	220.	130.
1.8	O&M Cost (K$/Year)	11.	----	----	14.	8.3	----	19.	14.	11.
0.70	Total Production Cost (cents/1,000 gal)	13.	----	----	15.	9.1	----	22.	15.	13.
10,001-25,000	Total Capital Cost (K$)	360.	----	----	440.	260.	----	640.	440.	360.
4.8	O&M Cost (K$/Year)	30.	----	----	37.	22.	----	51.	37.	30.
2.1	Total Production Cost (cents/1,000 gal)	9.5	----	----	12.	6.9	----	16.	12.	9.5
25,001-50,000	Total Capital Cost (K$)	720.	----	----	880.	500.	----	1300.	880.	720.
11.	O&M Cost (K$/Year)	70.	----	----	84.	53.	----	120.	84.	70.
5.0	Total Production Cost (cents/1,000 gal)	8.5	----	----	10.	6.1	----	15.	10.	8.5
50,001-75,000	Total Capital Cost (K$)	1100.	----	----	1400.	790.	----	2000.	1400.	1100.
18.	O&M Cost (K$/Year)	120.	----	----	150.	92.	----	200.	150.	120.
8.3	Total Production Cost (cents/1,000 gal)	7.9	----	----	9.6	5.7	----	14.	9.6	7.9
75,001-100,000	Total Capital Cost (K$)	1600.	----	----	2000.	1100.	----	2900.	2000.	1600.
26.	O&M Cost (K$/Year)	180.	----	----	210.	130.	----	300.	210.	180.
13.	Total Production Cost (cents/1,000 gal)	7.7	----	----	9.4	5.6	----	13.	9.4	7.7
100,001-500,000	Total Capital Cost (K$)	3000.	----	----	3700.	2000.	----	5400.	3700.	3000.
51.	O&M Cost (K$/Year)	360.	----	----	440.	290.	----	610.	440.	360.
27.	Total Production Cost (cents/1,000 gal)	7.2	----	----	8.8	5.2	----	13.	8.8	7.2
500,001-1,000,000	Total Capital Cost (K$)	11000.	----	----	14000.	7300.	----	21000.	14000.	11000.
210.	O&M Cost (K$/Year)	1700.	----	----	2000.	1300.	----	2700.	2000.	1700.
120.	Total Production Cost (cents/1,000 gal)	6.8	----	----	8.2	4.9	----	12.	8.2	6.8
1,000,000	Total Capital Cost (K$)	22000.	----	----	28000.	14000.	----	42000.	28000.	22000.
430.	O&M Cost (K$/Year)	3300.	----	----	4500.	3000.	----	6000.	4500.	3300.
270.	Total Production Cost (cents/1,000 gal)	6.5	----	----	7.8	4.7	----	11.	7.8	6.5

TABLE 7 - 24

Estimated Cost for Removing Heptachlor Using Packed Column Aeration - March 1989

System Size Category Population Range Design Flow (MGD) Average Daily Flow (MGD)		Influent								
		0.10 ug/L			1.0 ug/L			10. ug/L		
		Effluent (ug/L)			Effluent (ug/L)			Effluent (ug/L)		
		0.030	0.40	1.0	0.030	0.40	1.0	0.030	0.40	1.0
	Percent Removed	70.			97.	60.		99.7	96.	90.
25-100	Total Capital Cost (K$)	21.	----	----	37.	19.	----	50.	35.	29.
0.024	O&M Cost (K$/Year)	0.4	----	----	0.9	0.4	----	1.3	0.8	0.6
0.0056	Total Production Cost (cents/1,000 gal)	140.	----	----	250.	130.	----	350.	240.	200.
101-500	Total Capital Cost (K$)	39.	----	----	68.	35.	----	95.	64.	53.
0.087	O&M Cost (K$/Year)	1.1	----	----	2.1	1.0	----	3.0	2.0	1.6
0.024	Total Production Cost (cents/1,000 gal)	65.	----	----	110.	59.	----	160.	110.	89.
501-1,000	Total Capital Cost (K$)	64.	----	----	120.	57.	----	180.	120.	92.
0.27	O&M Cost (K$/Year)	2.5	----	----	5.0	2.2	----	7.2	4.7	3.7
0.086	Total Production Cost (cents/1,000 gal)	32.	----	----	61.	29.	----	90.	58.	46.
1,001-3,000	Total Capital Cost (K$)	100.	----	----	210.	90.	----	320.	200.	160.
0.65	O&M Cost (K$/Year)	5.3	----	----	10.	4.6	----	15.	9.9	7.9
0.23	Total Production Cost (cents/1,000 gal)	21.	----	----	42.	19.	----	63.	40.	31.
3,001-10,000	Total Capital Cost (K$)	200.	----	----	430.	170.	----	660.	410.	310.
1.8	O&M Cost (K$/Year)	14.	----	----	27.	12.	----	39.	25.	20.
0.70	Total Production Cost (cents/1,000 gal)	14.	----	----	30.	13.	----	46.	29.	22.
10,001-25,000	Total Capital Cost (K$)	420.	----	----	940.	350.	----	1500.	870.	670.
4.8	O&M Cost (K$/Year)	37.	----	----	74.	32.	----	110.	69.	54.
2.1	Total Production Cost (cents/1,000 gal)	11.	----	----	24.	9.6	----	37.	22.	17.
25,001-50,000	Total Capital Cost (K$)	850.	----	----	2000.	700.	----	3200.	1900.	1400.
11.	O&M Cost (K$/Year)	87.	----	----	170.	76.	----	250.	160.	130.
5.0	Total Production Cost (cents/1,000 gal)	10.	----	----	23.	8.6	----	34.	21.	16.
50,001-75,000	Total Capital Cost (K$)	1300.	----	----	3300.	1100.	----	5200.	3100.	2300.
18.	O&M Cost (K$/Year)	150.	----	----	290.	130.	----	420.	270.	220.
8.8	Total Production Cost (cents/1,000 gal)	9.5	----	----	21.	8.1	----	32.	20.	15.
75,001-100,000	Total Capital Cost (K$)	1900.	----	----	4700.	1600.	----	7500.	4300.	3200.
26.	O&M Cost (K$/Year)	220.	----	----	420.	190.	----	610.	400.	320.
13.	Total Production Cost (cents/1,000 gal)	9.3	----	----	21.	7.9	----	31.	19.	15.
100,001-500,000	Total Capital Cost (K$)	3600.	----	----	9000.	2900.	----	14000.	8300.	6200.
51.	O&M Cost (K$/Year)	440.	----	----	850.	390.	----	1200.	810.	650.
27.	Total Production Cost (cents/1,000 gal)	8.8	----	----	19.	7.5	----	29.	18.	14.
500,001-1,000,000	Total Capital Cost (K$)	14000.	----	----	35000.	11000.	----	56000.	32000.	24000.
210.	O&M Cost (K$/Year)	2000.	----	----	3700.	1800.	----	5300.	3500.	2800.
120.	Total Production Cost (cents/1,000 gal)	8.2	----	----	18.	7.0	----	27.	17.	13.
1,000,000	Total Capital Cost (K$)	27000.	----	----	71000.	22000.	----	110000.	66000.	48000.
430.	O&M Cost (K$/Year)	4500.	----	----	8200.	4100.	----	11000.	7700.	6700.
270.	Total Production Cost (cents/1,000 gal)	7.3	----	----	17.	6.7	----	25.	16.	12.

10552
5.554

TABLE 7-25

Estimated Cost for Vapor Phase Control with GAC

System Size Category Population Range Design Flow (MGD) Average Daily Flow (MGD)	Air: Water Ratio	ADSORPTION CAPACITY POOR 40	POOR 120	POOR 200	MODERATE 40	MODERATE 120	MODERATE 200	STRONG 40	STRONG 120	STRONG 200
25-100	Total Capital Cost (K$)	46	58	65	46	58	65	46	58	65
0.024	O&M Cost (K$/year)	0.20	0.30	0.30	0.20	0.20	0.20	0.10	0.20	0.20
0.0056	Total Production Cost (cents/1,000 gal)	270	350	390	270	340	380	270	340	380
101-500	Total Capital Cost (K$)	60	78	89	60	78	89	60	78	89
0.087	O&M Cost (K$/year)	1.0	1.2	1.4	0.6	0.8	1.0	0.4	0.6	0.8
0.024	Total Production Cost (cents/1,000 gal)	90	120	140	87	114	130	85	111	130
501-1,000	Total Capital Cost (K$)	79	110	135	79	110	135	79	110	135
0.27	O&M Cost (K$/year)	4	4	5	2.3	3.0	3.7	1.6	2.3	3.0
0.086	Total Production Cost (cents/1,000 gal)	41	54	70	37	51	62	35	48	60
1,001-3,000	Total Capital Cost (K$)	100	160	210	100	160	210	100	160	210
0.65	O&M Cost (K$/year)	10	12	13	6	8	10	4	6	8
0.23	Total Production Cost (cents/1,000 gal)	25	37	45	21	32	41	19	30	39
3,001-10,000	Total Capital Cost (K$)	150	280	380	150	280	380	150	280	380
1.8	O&M Cost (K$/year)	29	35	40	19	25	30	13	18	24
0.7	Total Production Cost (cents/1,000 gal)	18	27	33	14	23	29	12	20	27
10,001-25,000	Total Capital Cost (K$)	260	560	900	260	560	900	260	560	900
4.8	O&M Cost (K$/year)	88	100	120	56	74	90	38	55	73
2.1	Total Production Cost (cents/1,000 gal)	15	22	29	11	18	26	9	16	23
25,001-50,000	Total Capital Cost (K$)	440	1200	2000	440	1200	2000	440	1200	2000
11.0	O&M Cost (K$/year)	210	250	290	130	180	220	90	130	170
5.0	Total Production Cost (cents/1,000 gal)	14	21	29	10	18	25	8	15	22
50,001-75,000	Total Capital Cost (K$)	700	1900	3100	700	1900	3100	700	1900	3100
18.0	O&M Cost (K$/year)	370	440	510	240	310	380	160	230	310
8.8	Total Production Cost (cents/1,000 gal)	14	21	27	10	17	23	8	14	21
75,001-100,000	Total Capital Cost (K$)	970	2700	4200	970	2700	4200	970	2700	4200
26.0	O&M Cost (K$/year)	550	660	750	350	460	570	240	340	450
13.0	Total Production Cost (cents/1,000 gal)	14	21	26	10	16	22	7	14	20
100,001-500,000	Total Capital Cost (K$)	1800	5000	7900	1800	5000	7900	1800	5000	7900
51.0	O&M Cost (K$/year)	1100	1400	1600	700	950	1200	500	710	940
27.0	Total Production Cost (cents/1,000 gal)	13	20	26	9	16	22	7	13	19
500,001-1,000,000	Total Capital Cost (K$)	6600	18000	28000	6600	18000	28000	6600	18000	28000
210.0	O&M Cost (K$/year)	5000	6100	7000	3200	4200	5200	2200	3100	4200
120.0	Total Production Cost (cents/1,000 gal)	13	19	23	9	14	19	7	12	17
>1,000,000	Total Capital Cost (K$)	13000	34000	54000	13000	34000	54000	13000	34000	54000
430.0	O&M Cost (K$/year)	11300	14000	15600	7200	9500	12000	5000	7100	9400
270.0	Total Production Cost (cents/1,000 gal)	13	18	22	9	14	19	7	11	16

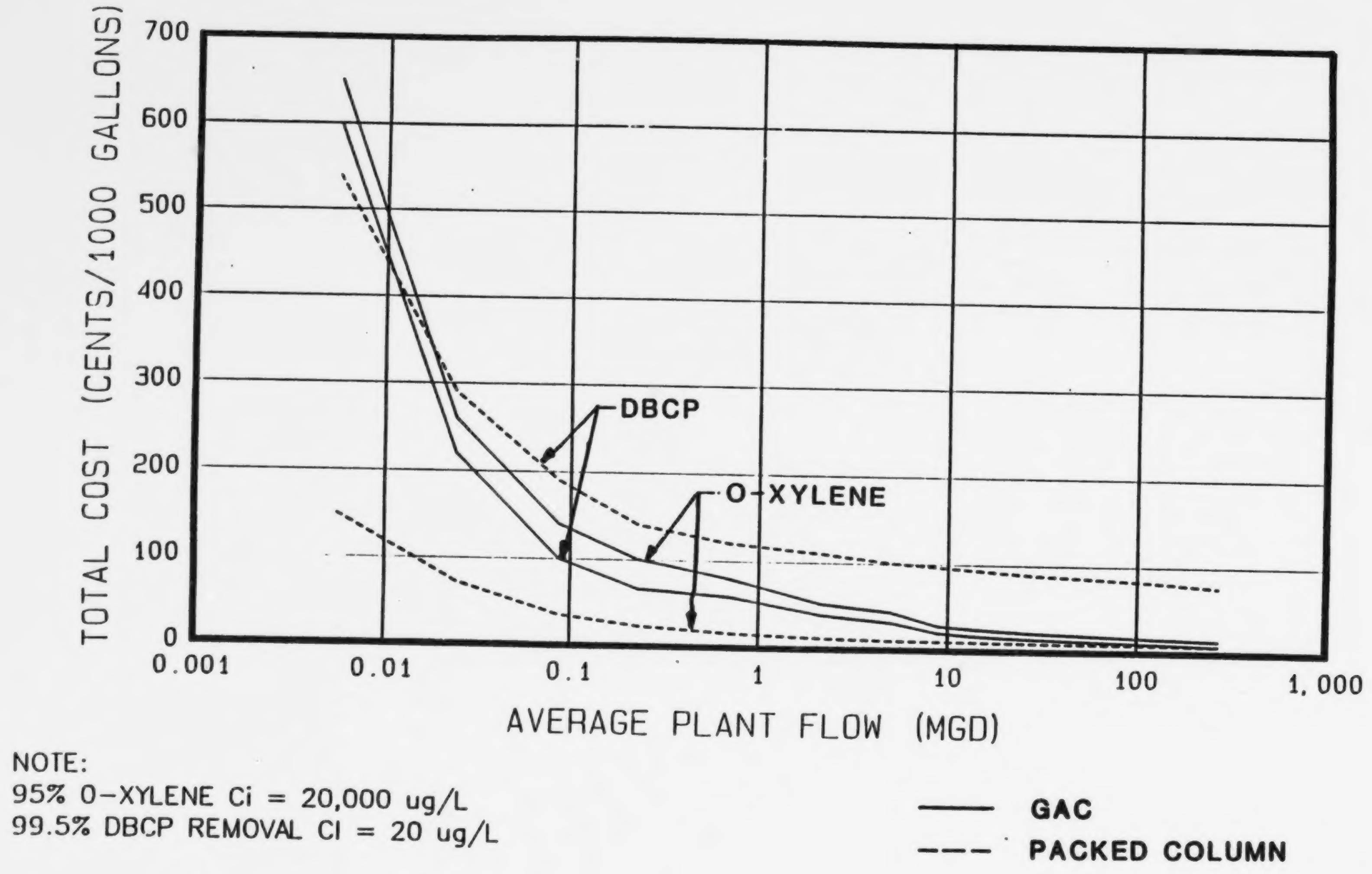
- Capital costs were divided into process equipment cost, support equipment cost, direct cost, and indirect cost. The operating costs are divided into power, maintenance, labor, and administrative.
- The process equipment included the column shell, column internals (i.e. liquid distributor, liquid redistributor, and packing material support plate), packing material, one blower, and one pump.
- The support equipment included assembly and installation of the above process equipment, a concrete air well which is a foundation for the packed column and a liquid reservoir, 200 feet of piping, instrumentation, air duct, and electrical connections.
- The total direct cost included all equipment installed at the site and is the sum of the process and support equipment.
- The indirect cost included all non-physical items required for the air stripping system. This includes sitework, design engineering, contractor overhead and profit, legal and financial, interest during construction, and contingencies.
- The total capital cost is the sum of the direct and indirect costs.

The operating cost is the sum of power, maintenance, labor, and administrative costs. The costs associated with each of these components were estimated and described as follows:

- The total production cost is the total annual cost divided by the volume of water treated per year.
- The blower costs were based on the projected volume of water treated per year.
- The maintenance costs were based on 10 percent and 4 percent of the mechanical and non-mechanical process equipment capital cost, respectively.
- The labor cost is based on a flat rate of 0.3 cents per 1,000 gallons of treated water and the volume of liquid treated per year.
- The administrative cost is based on 20 percent and 25 percent of the labor and maintenance cost respectively.

Summary

The choice between GAC adsorption and packed column aeration for removing SOCs from drinking water depends, to a large extent, on the economics of the two processes. All SOCs considered in this document were identified to be



NOTE:
95% O-XYLENE Ci = 20,000 ug/L
99.5% DBCP REMOVAL CI = 20 ug/L

COMPARISON OF COSTS
PACKED COLUMN VERSUS GAC ADSORPTION

FIGURE 7-4

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APPENDIX A

ESTIMATION OF CARBON USAGE RATES

APPENDIX A

ESTIMATION OF CARBON USAGE RATE

From Chapter 4 (isotherm evaluations)

$$\text{C.U. Rate} = \frac{C}{KC^{1/n}}$$

Where: C = SOC equilibrium concentration (mg/L)

K, 1/n = isotherm constants

Or:

$$\text{Carbon usage (lbs/thousand gallons)} = \frac{C}{K(Ci)^{1/n}}\ (\text{g/L}) \times 8.34\ \frac{(\text{lbs/KG})}{(\text{g/L})}$$

For example:

SOC = PCB (Arochlor 1254)

K = 13,724 (mg/g) $(\text{L/mg})^{1/n}$ (From Table 4-1)

1/n = 1.03 (From Table 4-1)

Influent concentration = 5 ug/L = 0.005 mg/L

$$\text{Carbon Usage} = \frac{(0.005)(\text{mg/L}) \times 8.34\ (\text{lbs/KG})/(\text{g/L})}{13{,}724\ (\text{mg/g})(\text{L/mg})^{1/n} \times (0.005(\text{mg/L}))^{1.03}}$$

$$= 0.00071\ \text{lbs/KGAL}$$

APPENDIX B

SUMMARY OF GAC ISOTHERM STUDIES

APPENDIX B

SUMMARY OF GAC ISOTHERM STUDIES (1)

SOC	Mol. Wt.	Water Type (2)	Temperature	pH	1/n	(umole/g)[(L/umole)]$^{1/n}$	(mg/g)[(L/mg)]$^{1/n}$	Reference
Alachlor	269.8	Distilled	Room	6.2	0.26	1275.0	483.55	Miltner (1987)
		River Water	Room	8.0	0.38	328.0	145.58	Miltner (1987)
		Ground Water	Room	7.7	0.33	1457.0	605.65	Miltner (1987)
Aldicarb	190.3	Distilled	Room	6.3-6.6	0.40	360.0	133.01	Miltner (1987)
		River Water	Room	8.2	0.41	194.0	72.88	Miltner (1987)
Atrazine	215.7	Ground Water	Room	7.6	0.36	787.0	294.86	Miltner (1987)
Carbofuran	221.3	Distilled	Room	4.3	0.41	673.0	276.41	Miltner (1987)
		River Water (filtered)	Room	7.9-8.2	0.36	376.0	143.21	Miltner (1987)
Chlordane	409.8	Distilled	Room	-	0.33	346.0	190.33	Miltner (1987)
		Distilled	-	5.3	0.38	-	245.00	Dobbs and Cohen (1980)
Cis-1,2-dichloroethylene	97.0	Distilled	Room	6.6-8.0	0.59	30.5	11.72	Miltner (1987)
		Distilled	14 C	7.5-8.0	0.56	47.0	16.83	Miltner (1987)
		Ground Water	Room	8.0	0.63	23.0	9.70	Miltner (1987)
		Ground Water	14 C	6.3-6.4	0.36	16.7	3.75	Miltner (1987)
		River Water	Room	8.0	0.64	29.4	12.69	Miltner (1987)
DBCP	236.4	Distilled	Room	6.2-6.6	0.51	465.0	229.35	Miltner (1987)
		River Water	Room	8.1-8.5	0.46	206.0	94.54	Miltner (1987)
		Ground Water	-	6.5	0.60	-	1260.00	Canonie Environmental Services (1981)
o-dichlorobenzene	147.0	Distilled	Room	5.6-5.8	0.38	865.0	263.49	Miltner (1987)
		Distilled	-	5.5	0.43	-	129.00	Dobbs and Cohen (1980)
		River Water	Room	8.1	0.58	1039.0	464.41	Miltner (1987)

SOC	Mol. Wt.	Water Type (2)	Temperature	pH	1/n	(umole/g)[(L/umole)]$^{1/n}$	(mg/g)[(L/mg)]$^{1/n}$	Reference
1,2-dichloropropane	113.0	Distilled	Room	6.1-7.3	0.59	46.6	19.06	Miltner (1987)
		River Water	Room	8.1	0.48	35.8	11.52	Miltner (1987)
		Distilled	-	5.3	0.60	-	5.86	Dobbs and Cohen (1980)
2,4-D	221.0	Distilled (3)	Room	-	0.27	194.0	64.46	Miltner (1987)
		Distilled	-	7.0	0.56	-	118.00	Aly and Faust (1965)
Ethyl benzene	106.2	Distilled	Room	5.6-6.9	0.53	507.0	176.69	Miltner (1987)
		Distilled	13.8 C	7.5-8.0	0.29	694.0	141.19	Miltner (1987)
		Distilled	-	-	0.40	-	100.00	EL-Dib and Badaway (1979)
EDB	187.9	Distilled	Room	6.2-7.1	0.46	53.9	21.85	Miltner (1987)
		River Water	Room	8.0	0.54	69.3	32.12	Miltner (1987)
		Distilled	10 C	6.0	0.46	118.0	47.84	Miltner (1987)
		Distilled	-	7.0	0.97	-	85.70	MPI (1986)
		Ground Water	-	5.9	0.35	-	9.00	Canonie Environmental Services (1981)
Heptachlor	373.5	Distilled	-	7.0	0.97	-	1158.00	MPI (1986)
		Distilled	-	5.3	0.39	-	114.00	Dobbs and Cohen (1980)
		Distilled (4)			0.92	1110.0	1025.91	Dobbs and Cohen (1980)
Heptachlor Epoxide	389.8	Distilled (4)	Room	-	0.75	2020.0	1596.14	Miltner (1987)
		Distilled	-	7.0	0.55	-	1660.00	MPI (1986)
		Distilled	-	5.3	0.70	-	1038.00	Dobbs and Cohen (1980)
Lindane	290.9	Distilled	Room	4.2-6.9	0.43	606.0	299.75	Miltner (1987)
		River Water (filtered)	Room	7.8-8.1	0.39	455.0	214.21	Miltner (1987)
Methoxychlor	345.7	Distilled (5)	Room	-	0.36	223.0	112.99	Miltner (1987)
		Tap Water	-	-	0.46	-	136.00	Steiner and Singley (1979)

SOC	Mol. Wt.	Water Type (2)	Temperature	pH	1/n	(umole/g)[(L/umole)]$^{1/n}$	(mg/g)[(L/mg)]$^{1/n}$	Reference
Monochlorobenzene	112.6	Distilled	Room	6.5	0.35	418.0	101.06	Miltner (1987)
		River Water (filtered)	Room	8.0	0.31	381.0	84.41	Miltner (1987)
		Distilled	-	7.4	0.99	-	91.00	Dobbs and Cohen (1980)
PCBs								
- Aroclor 1016	188.0	Organic Free Water	-	-	0.66	-	328.50	Weber and Pirbazari (1982)
- Aroclor 1254	326.0	Organic Free Water	-	-	1.14	-	1920.00	Weber and Pirbazari (1982)
		Distilled	Room	7.0	1.03	13270.0	13723.80	Miltner (1987)
Pentachlorophenol	266.4	Distilled	Room	4.6-6.8	0.34	1062.0	443.53	Miltner (1987)
		River Water	Room	8.1	0.37	403.0	173.97	Miltner (1987)
		Distilled	-	7.0	0.42	-	150.00	Dobbs and Cohen (1980)
Silvex	255.5	Distilled	Room	7.0	0.38	479.0	205.55	Miltner (1987)
Styrene	104.0	Distilled	Room	9.4	0.48	1083.0	333.80	Miltner (1987)
Tetrachloroethylene	165.8	Distilled	Room	5.1-7.6	0.52	341.20	143.00	Miltner (1987)
				5.3	0.56	-	50.80	Dobbs and Cohen (1980)
Toluene	92.1	Distilled	Room	4.6-6.7	0.45	356.0	95.91	Miltner (1987)
		Ground Water	Room	7.5	0.37	348.0	76.56	Miltner (1987)
		Distilled	13.8 C	7.7	0.33	476.0	96.33	Miltner (1987)
		Distilled	-	-	0.30	-	96.00	EL-Dib and Badaway (1979)
		Distilled	-	5.6	0.44	-	26.10	Dobbs and Cohen (1980)
Toxaphene	412.0	Distilled	Room	7.0	0.74	1182.0	938.62	Miltner (1987)
		Distilled	Room	-	0.26	128.0	66.41	Miltner (1987)
		Distilled	-	-	0.25	-	364.40	Bernadin et al (1975)

SOC	Mol. Wt.	Water Type (2)	Temperature	pH	1/n	(umole/g)[(L/umole)]$^{1/n}$	(mg/g)[(L/mg)]$^{1/n}$	Reference
Trans-1,2-dichloroethylene	97.0	Distilled	Room	6.3-6.7	0.45	50.5	13.99	Miltner (1987)
		River Water	Room	7.6	0.39	38.5	9.27	Miltner (1987)
		Distilled	-	6.7	0.51	-	3.05	Dobbs and Cohen (1980)
Xylenes	106.2							
o-		Distilled	Room	6.3-6.45	0.47	603.0	183.69	Miltner (1987)
		Ground Water	Room	7.6	0.47	838.0	255.27	Miltner (1987)
		Distilled	13.8 C	7.6	0.26	897.0	170.61	Miltner (1987)
		Distilled	-	-	0.22	-	120.00	EL-Dib and Badaway (1979)
m-		Distilled	Room	6.7	0.75	410.0	234.03	Miltner (1987)
		Distilled	13.8 C	7.5-8.0	0.25	1043.0	193.98	Miltner (1987)
p-		Distilled	Room	6.9	0.42	740.0	201.51	Miltner (1987)
		Ground Water	Room	6.4	0.46	611.0	182.00	Miltner (1987)
		Distilled	-	7.3	0.19	-	85.00	Dobbs and Cohen (1980)

Notes:

1. "-" = Not Reported
2. Carbon type = Filtrasorb 400 unless otherwise noted.
3. Carbon type = Aqua Nuchara
4. Carbon type = Filtrasorb 300
5. Carbon type = Nuchar special

APPENDIX C

SUMMARY OF PILOT AND FULL-SCALE GAC STUDIES

APPENDIX C

SUMMARY OF PILOT AND FULL-SCALE GAC STUDIES

(4) SOC/Type	* Source of Data	Reference	Solution and Organic Matrix	EBCT (min)	Concentration (ug/L)		GAC Usage Rate (lb/1,000 gal)
					Influent	Effluent	
Alachlor							
F	EPA Study Fremont, OH	Baker (1983)	alachlor	9	0.7-5	0.1-0.7	-
			atrazine	9	0.5-8	0.5-1.5	-
Aldicarb							
P	Suffolk County, NY	Moran (1983)	aldicarb	-	21	7	1.04
			carbofuran	-	3		1.04
			aldicarb	-	105	7	0.54
			carbofuran	-	25		0.54
			aldicarb	-	53	7	0.26
			carbofuran	-	42		0.26
			aldicarb	-	262	7	1.12
			carbofuran	-	9		1.12
			aldicarb	-	105	7	0.35
			carbofuran	-	24		0.35
			aldicarb	-	151	7	1.38
			carbofuran	-	57		1.38
			aldicarb	-	64	7	0.39
			carbofuran	-	25		0.39
			aldicarb	-	36	7	0.56
			carbofuran	-	ND		0.56

APPENDIX C (continued)
SUMMARY OF PILOT AND FULL-SCALE GAC STUDIES

(4) SOC/Type	Source of Data	Reference	Solution and Organic Matrix	EBCT (min)	Concentration (ug/L)		GAC Usage Rate (lb/1,000 gal)
					Influent	Effluent	
Aldicarb Sulfone							
P	Suffolk County, NY	Miltner (1987)	aldicarb sulfone	15	17.5	4.4	.195
					17.5	13.1	.147
			aldicarb sulfone	10	19.5	4.9	.200
					19.5	14.6	.131
			aldicarb sulfone	5	29.5	7.4	.268
				5	29.5	22.2	.142
			aldicarb sulfoxide	5	20.5	5.1	.292
				5	20.5	15.4	.129
			carbofuran	5	8.5	2.1	.089
			1,2-dichloropropane	5	34.1	8.5	.316
				5	34.1	25.6	.133
Aldicarb Sulfoxide							
P	Suffolk County, NY	Miltner (1987)	aldicarb sulfoxide	15	16	4.0	.196
					16	12.0	.138
			aldicarb sulfoxide	10	16.5	4.1	.196
					16.5	12.1	.128
			aldicarb sulfoxide	5	20.5	5.1	.292
				5	20.5	15.4	.129

APPENDIX C (continued)

SUMMARY OF PILOT AND FULL-SCALE GAC STUDIES

(4) SOC/Type	Source of Data	Reference	Solution and Organic Matrix	EBCT (min)	Concentration (ug/L)		GAC Usage Rate (lb/1,000 gal)
					Influent	Effluent	
			aldicarb sulfone	5	29.5	7.4	.268
				5	29.5	22.2	.142
			carbofuran	5	8.5	2.1	.089
			1,2-dichloropropane	5	34.1	8.5	.316
				5	34.1	25.6	.133
Chlordane							
F	Hazardous Material Spills Treatment Strongstown, PA	LaFornara (1978)	chlordane	17	13	.35	59.2
			heptachlor	17	6.1	.06	59.2
			dieldrin and aldrin	17	19.5	<.59	59.2
(5) P	Gulf South Research, Inc.	Bell et al (1984)	chlordane	-	50	2.5-8	.925
			p-dichlorobenzene	-	10	0.1-5.5	.925
			hexachlorobenzene	-	10	ND	.925
DBCP							
P	Lathrop, CA	Canonie Environmental Services Corp. (1981)	EDB	30	7.1-10.8	ND	<.69
			sulfolane	30	1,340-2,800	2,000	3-3.7
			DBCP	30	531-1.566	25	1.5
P	University Research	Pirabarzari, Weber, et al (1983)	DBCP	10	18	ND	<.01
			DCE	5	21	ND	<1.93 but >.66
F	San Joaquin Valley, CA	O'Dahl, Thomas (1985)	DBCP	-	71-184	<.1	.31
			EDB	-	8-19	ND	.31

APPENDIX C (continued)
SUMMARY OF PILOT AND FULL-SCALE GAC STUDIES

(4) SOC/Type	Source of Data	Reference	Solution and Organic Matrix	EBCT (min)	Concentration (ug/L) Influent	Concentration (ug/L) Effluent	GAC Usage Rate (lb/1,000 gal)
O-dichlorobenzene							
F	Orange County Water District	McCarty & Reinhard (1980)	o-dichlorobenzene	-	.01	.002	2.4
			chlorobenzene-o-xylene	-	.09	.049	2.4
			ethylbenzene	-	.06	.033	2.4
			o-dichlorobenzene	-	.02	.002	1.2
			chlorobenzene-o-xylene	-	.11	.041	1.2
			m-xylene	-	.05	.025	1.2
			ethylbenzene	-	.02	.017	1.2
			styrene	-	.03		
1,2-dichloropropane							
P	Suffolk County, NY	Miltner (1987)	1,2-dichloropropane	15	20	5	.225
					20	15	.165
			1,2-dichloropropane	10	22	5.5	.249
					22	16.5	.152
			1,2-dichloropropane	5	34.1	8.5	.316
				5	34.1	25.6	.133
			aldicarb sulfoxide	5	20.5	5.1	.292
				5	20.5	15.4	.129
			aldicarb sulfone	5	29.5	7.4	.268
				5	29.5	22.2	.142
			carbofuran	5	8.5	2.1	.089

APPENDIX C (continued)
SUMMARY OF PILOT AND FULL-SCALE GAC STUDIES

(4) SOC/Type	Source of Data	Reference	Solution and Organic Matrix	EBCT (min)	Concentration (ug/L)		GAC Usage Rate (lb/1,000 gal)
					Influent	Effluent	
Dichloroethylene							
P	University Research	Pirabarzari, Weber, et al (1983)	DBCP	10	18	ND	<.01
			DCE	5	21	ND	<1.93 but >.66
P	USEPA - DWRD New Hampshire	Love & Eilers (1982)	cis-1,2-DCE	9	6	.1	.254
			TCE	9	120-276	ND	NC
	Connecticut	Love & Eilers (1982)	cis-1,2-DCE	-	2	.1	.122
			TCE	-	1-10	.1	NC
			1,1,1-TCA	-	38	.1	NC
P	Wausau, Wisconsin	Miltner (1987)	cis-1,2-DCE	32	55	14	.262
			cis-1,2-DCE	32	55	42	.194
			cis-1,2-DCE	21	75	19	.252
			cis-1,2-DCE	21	75	56	.220
			cis-1,2-DCE	10	88.1	22	.294
			cis-1,2-DCE	10	88.1	66	.176
			cis-1,2-DCE	5	61	15	.35
			cis-1,2-DCE	5	61	46	.174
			cis-1,2-DCE	3	72.8	18	.476
			cis-1,2-DCE	3	72.8	55	.187
			cis-1,2-DCE	1	79.8	20	.49
			cis-1,2-DCE	1	79.8	60	.125

APPENDIX C (continued)
SUMMARY OF PILOT AND FULL-SCALE GAC STUDIES

(4) SOC/Type	Source of Data	Reference	Solution and Organic Matrix	EBCT (min)	Concentration (ug/L)		GAC Usage Rate (lb/1,000 gal)
					Influent	Effluent	
			ethyl benzene	1	4.5	1.13	.071
			ethyl benzene	1	4.5	3.34	.010
			toluene	1	24.55	6.1	.066
			toluene	1	24.55	18.4	.027
			m-xylene	1	5.45	1.36	.069
			m-xylene	1	5.45	4.09	.012
			o/p-xylene	1	9.0	2.25	.172
			o/p-xylene	1	9.0	6.75	.013
P	Great Miami Aquifer, Ohio	Miltner (1987)	cis-1,2-DCE	6.2	25.72	6.4	.463
			cis-1,2-DCE	6.2	25.72	19.3	.206
			cis-1,2-DCE	6.2	19.35	4.8	.464
			cis-1,2-DCE	6.2	19.35	14.5	.257
			cis-1,2-DCE	12.4	20.84	5.2	.421
			cis-1,2-DCE	12.4	20.84	15.6	.266
F	Wausau, Wisconsin	Miltner (1987)	cis-1,2-DCE	7.4	95.4	23.9	.434
			cis-1,2-DCE	7.4	95.4	71.6	.247
			cis-1,2-DCE	12.7	77.4	19.4	.299
			cis-1,2-DCE	12.7	77.4	58.1	.199

APPENDIX C (continued)
SUMMARY OF PILOT AND FULL-SCALE GAC STUDIES

(4) SOC/Type	Source of Data	Reference	Solution and Organic Matrix	EBCT (min)	Concentration (ug/L)		GAC Usage Rate (lb/1,000 gal)
					Influent	Effluent	
EDB							
P	Lathrop, CA	Canonie Env. Services, Inc. July, 1983	EDB	30	7.1-10.8	ND	<.69
			Sulfolane	30	1,340-2,800	2,000	3-3.7
			DBCP	30	531-1,566	25	1.5
		ES&E, Inc., 1981	EDB	-	96	6.3	.27
				-	45	5.5	.11
				-	90	8.9	.13
F	San Joaquin Valley, CA	Thomas O. Dahl (1985)	DBCP (ground water)	-	71-184	<.1	.31
			EDB (ground water)	-	8-19	ND	
Ethyl benzene							
P	Wausau, Wisconsin	Miltner (1987)	cis-1,2-DCE	1	79.8	20	.49
			cis-1,2-DCE	1	79.8	60	.125
			ethyl benzene	1	4.5	1.13	.071
			ethyl benzene	1	4.5	3.34	.010
			toluene	1	24.55	6.1	.066
			toluene	1	24.55	18.4	.027
			m-xylene	1	5.45	1.36	.069
			m-xylene	1	5.45	4.09	.012
			o/p-xylene	1	9.0	2.25	.172
			o/p-xylene	1	9.0	6.75	.013

APPENDIX C (continued)
SUMMARY OF PILOT AND FULL-SCALE GAC STUDIES

SOC/Type (4)	Source of Data	Reference	Solution and Organic Matrix	EBCT (min)	Concentration (ug/L) Influent	Concentration (ug/L) Effluent	GAC Usage Rate (lb/1,000 gal)
F	Orange County Water District	McCarty & Reinhard (1980)	o-dichlorobenzene	-	.01	.002	2.4
			chlorobenzene-o-xylene	-	.09	.049	2.4
			ethylbenzene	-	.06	.033	2.4
			o-dichlorobenzene	-	.02	.002	1.2
			chlorobenzene-o-xylene	-	.11	.041	1.2
			m-xylene	-	.05	.025	1.2
			ethylbenzene	-	.02	.017	1.2
			styrene	-	.03	.018	1.2
Lindane							
P	Lake Constance, Switzerland	Morgeli (1972)	lindane	-	50	.014 (6)	-
				-	50	2.6	-
				-	50	.08	-
Methoxychlor							
P		Steiner & Singley (1979)	methoxychlor	-	1	ND	-
				-	5	ND	-
				-	10	ND	-
PCBs - polychlorinated biphenyls							
F	Hazardous Material Spills Treatment Trailer Seattle, WA	Lafornara (1978)	PCB-aroclor 1242	30-40	3	<.075	<9.92
	New York State	O'Brien & Gere (1982)	PCB	7.5	1	<.1	<.1

APPENDIX C (continued)
SUMMARY OF PILOT AND FULL-SCALE GAC STUDIES

SOC/Type (4)	Source of Data	Reference	Solution and Organic Matrix	EBCT (min)	Concentration (ug/L) Influent	Concentration (ug/L) Effluent	GAC Usage Rate (lb/1,000 gal)
Pentachlorophenol							
P	Hazardous Material Spills Treatment Trailer Seattle, WA		pentachlorophenol	-	10,000 (7)	<1	<82.3
P	Thunderbay, Ontario	Jank (1980)	pentachlorophenol	-	3.4	.03	2.24
Styrene							
F	Orange County Water District	McCarty & Reinhard (1980)	o-dichlorobenzene	-	.02	.002	1.2
			chlorobenzene-o-xylene	-	.11	.041	1.2
			m-xylene	-	.05	.025	1.2
			ethylbenzene	-	.02	.017	1.2
			styrene	-	.03	.018	1.2
Toxaphene							
F	Hazardous Material Spills Treatment Trailer Seattle, WA	Lafornara (1978)	toxaphene	-	36 (8)	<1	<72
M-xylene							
F	Orange County Water District	McCarty & Reinhard (1980)	o-dichlorobenzene	-	.02	.002	1.2
			chlorobenzene-o-xylene	-	.11	.041	1.2
			m-xylene	-	.05	.025	1.2
			ethylbenzene	-	.02	.017	1.2
			styrene	-	.03	.018	1.2

Notes:

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1. "-" = Not Available
2. "NC" = Not Calculated
3. "ND" = Not Detectable
4. Legend: F = full scale; P = pilot scale
5. Culligan filters
6. Different carbon types used.
7. Influent to diatomaceous earth.
8. Influent to mixed media filter.

APPENDIX D

CARBON USAGE RATE COMPARISON

APPENDIX D

COMPARISON OF FIELD DATA AND MODEL-PREDICTED CARBON USAGE RATES

Compound	Concentration Average Influent (ug/L)	Concentration Effluent (ug/L)	Carbon Usage Rate (lbs/Kgal) Type I (1)	Carbon Usage Rate (lbs/Kgal) Type IIIx (2)	Carbon Usage Rate (lbs/Kgal) Type IVx (3)	Ratio IIIx or IVx :I	EBCT (min)	TOC (mg/L)	Water Source
Aldicarb	19.9	0.5	0.00677	0.301	---	44.46	12.0	---	Suffolk GW
		2.5	0.00653	0.193	---	29.56	12.0	---	Suffolk GW
		7.5	0.0062	0.142	---	22.90	12.0	---	Suffolk GW
		12.5	0.00593	0.124	---	20.91	12.0	---	Suffolk GW
		17.5	0.00544	0.113	---	20.77	12.0	---	Suffolk GW
		19.9	0.00452	0.109	---	24.12	12.0	---	Suffolk GW
cis-1,2-Dichloroethylene	79.8	0.798	infinite	infinite	---	0.00	1.01	8.35	Wausau GW
		20	0.49	0.49	---	1.00	1.01	8.35	Wausau GW
		60	0.114	0.125	---	1.10	1.01	8.35	Wausau GW
		79.8	0.038	0.092	---	2.42	1.01	8.35	Wausau GW
	72.8	0.728	0.442	2.27	---	5.14	3.09	8.35	Wausau GW
		18	0.205	0.476	---	2.32	3.09	8.35	Wausau GW
		55	0.139	0.187	---	1.35	3.09	8.35	Wausau GW
		72.8	0.076	0.145	---	1.91	3.09	8.35	Wausau GW
	61.0	0.61	0.241	0.708	---	2.94	5.08	8.35	Wausau GW
		15	0.17	0.35	---	2.06	5.08	8.35	Wausau GW
		46	0.134	0.174	---	1.30	5.08	8.35	Wausau GW
		61	0.089	0.139	---	1.56	5.08	8.35	Wausau GW
	88.1	0.881	0.217	0.433	---	2.00	10.35	8.35	Wausau GW
		22	0.188	0.294	---	1.56	10.35	8.35	Wausau GW
		66	0.168	0.176	---	1.05	10.35	8.35	Wausau GW
		88.1	0.133	0.149	---	1.12	10.35	8.35	Wausau GW
	75.0	0.75	0.18	0.296	---	1.64	21.18	8.35	Wausau GW
		19	0.168	0.252	---	1.50	21.18	8.35	Wausau GW
		56	0.16	0.22	---	1.38	21.18	8.35	Wausau GW
		75	0.141	0.175	---	1.24	21.18	8.35	Wausau GW
	55.0	0.55	0.149	0.318	---	2.13	32.25	8.35	Wausau GW
		14	0.144	0.262	---	1.82	32.25	8.35	Wausau GW
		42	0.139	0.194	---	1.40	32.25	8.35	Wausau GW
		55	0.127	0.172	---	1.35	32.25	8.35	Wausau GW
	25.72	0.2572	0.2	1.23	---	6.15	6.20	6.00	Great Miami Aquifer
		6.4	0.174	0.463	---	2.66	6.20	6.00	Great Miami Aquifer
		19.3	0.148	0.206	---	1.39	6.20	6.00	Great Miami Aquifer
		25.72	0.108	0.161	---	1.49	6.20	6.00	Great Miami Aquifer

APPENDIX D (continued)

COMPARISON OF FIELD DATA AND MODEL-PREDICTED CARBON USAGE RATES

Compound	Concentration Average Influent (ug/L)	Concentration Effluent (ug/L)	Carbon Usage Rate (lbs/Kgal) Type I (1)	Carbon Usage Rate (lbs/Kgal) Type IIIx (2)	Carbon Usage Rate (lbs/Kgal) Type IVx (3)	Ratio IIIx or IVx :I	EBCT (min)	TOC (mg/L)	Water Source
1,2-Dichloropropane	20.0	0.2	0.103	0.281	---	2.73	15.00	2.00	Suffolk GW
		1	0.101	0.267	---	2.64	15.00	2.00	Suffolk GW
		2.5	0.0978	0.248	---	2.54	15.00	2.00	Suffolk GW
		5	0.0948	0.225	---	2.37	15.00	2.00	Suffolk GW
		7.5	0.0924	0.202	---	2.19	15.00	2.00	Suffolk GW
		12.5	0.0881	0.174	---	1.98	15.00	2.00	Suffolk GW
		15	0.085	0.165	---	1.94	15.00	2.00	Suffolk GW
		17.5	0.0812	0.15	---	1.85	15.00	2.00	Suffolk GW
		20	0.069	0.146	---	2.12	15.00	2.00	Suffolk GW
Ethyl Benzene	4.5	0.045	infinite	infinite	---	0.00	1.01	8.35	Wausau GW
		1.13	0.002	0.071	---	35.50	1.01	8.35	Wausau GW
		3.34	0.001	0.01	---	10.00	1.01	8.35	Wausau GW
		4.5	0.0004	0.0064	---	16.00	1.01	8.35	Wausau GW
Toluene	24.55	0.02455	infinite	0.215	---	0.00	1.01	8.35	Wausau GW
		6.1	0.013	0.066	---	5.08	1.01	8.35	Wausau GW
		18.4	0.006	0.027	---	4.50	1.01	8.35	Wausau GW
		24.55	0.002	0.021	---	10.50	1.01	8.35	Wausau GW
m-Xylene	5.45	0.0545	infinite	infinite	---	0.00	1.01	8.35	Wausau GW
		1.36	0.001	0.069	---	69.00	1.01	8.35	Wausau GW
		4.09	0.0007	0.013	---	18.57	1.01	8.35	Wausau GW
		5.45	0.0002	0.0073	---	36.50	1.01	8.35	Wausau GW
o/p-Xylene	9.0	0.09	infinite	infinite	---	0.00	1.01	8.35	Wausau GW
		2.25	0.002	0.172	---	86.00	1.01	8.35	Wausau GW
		6.75	0.0011	0.013	---	11.82	1.01	8.35	Wausau GW
		9	0.0004	0.0088	---	22.00	1.01	8.35	Wausau GW

Note:

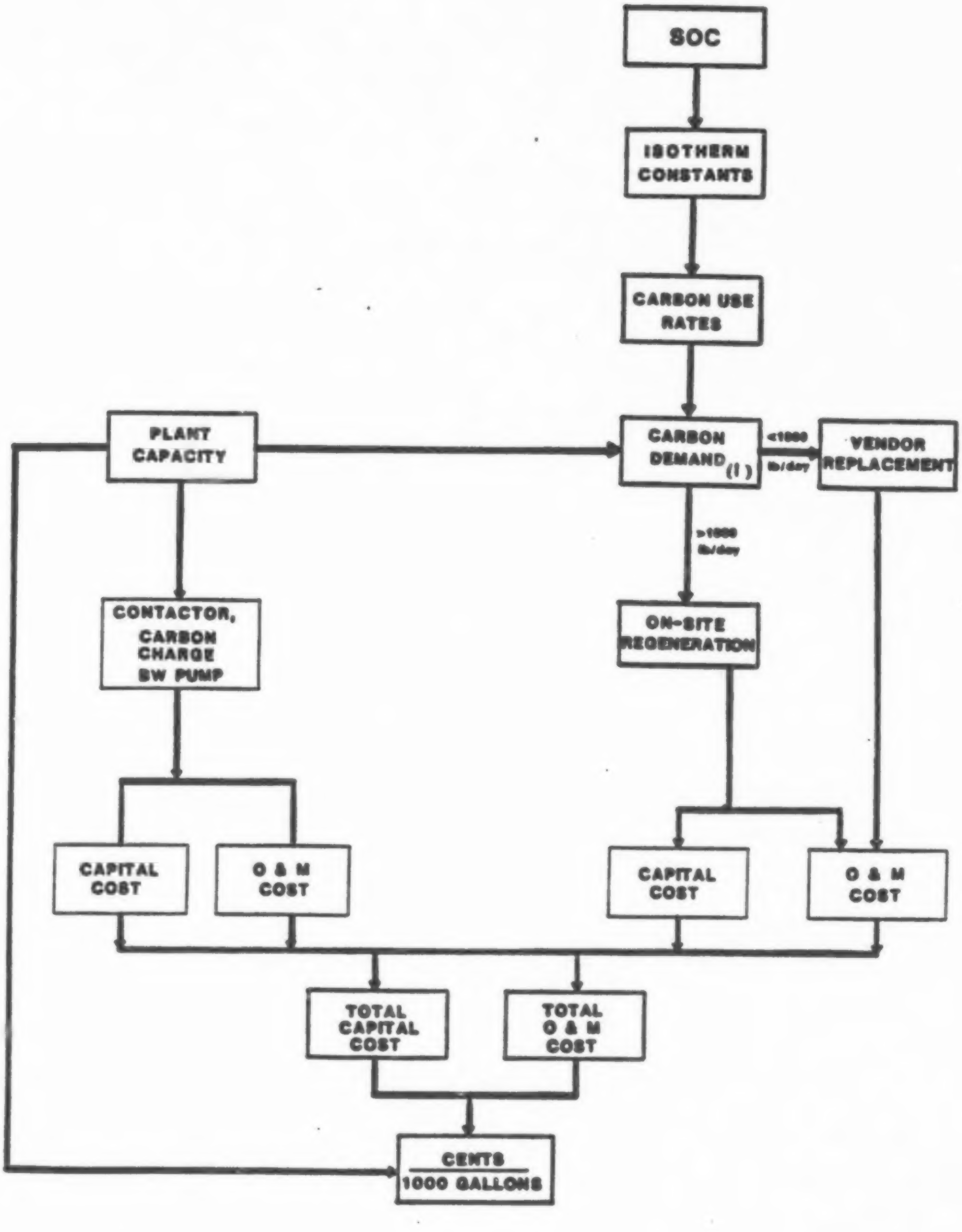
(1) Type I carbon usage rates are HSDM model predictions using distilled water isotherm values.

(2) Type IIIx data are actual carbon usage rates determined at the indicated concentrations and design criteria through pilot-scale testing.

(3) Type IVx data are actual carbon usage rates determined at the indicated concentrations and design criteria through full-scale testing.

APPENDIX E

FLOW-CHART FOR DEVELOPING GAC FACILITY COSTS


SOC
ISOTHERM CONSTANTS
CARBON USE RATES
PLANT CAPACITY
CARBON DEMAND (1)
<1000 lb/day
VENDOR REPLACEMENT
>1000 lb/day
CONTACTOR, CARBON CHARGE BW PUMP
ON-SITE REGENERATION
CAPITAL COST
O & M COST
CAPITAL COST
O & M COST
TOTAL CAPITAL COST
TOTAL O & M COST
CENTS / 1000 GALLONS

(1) CARBON DEMAND= CARBON USE RATE x FLOW

FLOW-CHART FOR DEVELOPING GAC FACILITY COSTS

APPENDIX F

GAC COSTS FOR INDIVIDUAL PHASE II SOC'S

GAC Adsorption -- Costs for Removing===> Alachlor

	Influent (ug/L)	10.00			50.00			100.00		
Population Range	Effluent (ug/L)	0.60	2.00	6.00	0.60	2.00	6.00	0.60	2.00	6.00
Design Flow (MGD)										
Average Daily Flow (MGD)	Percent Removed	94.00	80.00	40.00	98.80	96.00	88.00	99.40	98.00	94.00
25-100	Total Capital Cost (K$)	125	125	125	125	125	125	125	125	125
0.024	O&M Cost (K$/year)	4	4	4	4	4	4	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	910	910	910	910	910	910	910	910	910
101-500	Total Capital Cost (K$)	190	190	190	190	190	190	190	190	190
0.087	O&M Cost (K$/year)	5	5	5	5	5	5	5	5	5
0.024	Total Production Cost (cents/1,000 gal)	310	310	310	310	310	310	310	310	310
501-1,000	Total Capital Cost (K$)	300	300	300	300	300	300	300	300	300
0.27	O&M Cost (K$/year)	8	8	8	8	8	8	8	8	8
0.086	Total Production Cost (cents/1,000 gal)	140	140	140	140	140	140	140	140	140
1,001-3,300	Total Capital Cost (K$)	480	480	480	480	480	480	480	480	480
0.65	O&M Cost (K$/year)	14	14	14	14	14	14	14	14	14
0.23	Total Production Cost (cents/1,000 gal)	80	80	80	80	80	80	80	80	80
3,301-10,000	Total Capital Cost (K$)	800	800	800	800	800	800	800	800	800
1.8	O&M Cost (K$/year)	30	30	30	30	30	30	30	30	30
0.7	Total Production Cost (cents/1,000 gal)	49	49	49	49	49	49	49	49	49
10,001-25,000	Total Capital Cost (K$)	1700	1700	1700	1700	1700	1700	1700	1700	1700
4.8	O&M Cost (K$/year)	70	70	70	70	70	70	70	70	70
2.1	Total Production Cost (cents/1,000 gal)	36	36	36	36	36	36	36	36	36
25,001-50,000	Total Capital Cost (K$)	3300	3300	3300	3300	3300	3300	3300	3300	3300
11.0	O&M Cost (K$/year)	130	130	130	130	130	130	130	130	130
5.0	Total Production Cost (cents/1,000 gal)	29	29	29	29	29	29	29	29	29
50,001-75,000	Total Capital Cost (K$)	5100	5100	5100	5100	5100	5100	5100	5100	5100
18.0	O&M Cost (K$/year)	200	200	200	200	200	200	200	200	200
8.8	Total Production Cost (cents/1,000 gal)	25	25	25	25	25	25	25	25	25
75,001-100,000	Total Capital Cost (K$)	6500	6500	6500	6500	6500	6500	6500	6500	6500
26.0	O&M Cost (K$/year)	300	300	300	300	300	300	300	300	300
13.0	Total Production Cost (cents/1,000 gal)	23	23	23	23	23	23	23	23	23
100,001-500,000	Total Capital Cost (K$)	13000	13000	13000	13000	13000	13000	13000	13000	13000
51.0	O&M Cost (K$/year)	400	400	400	400	400	400	400	400	400
27.0	Total Production Cost (cents/1,000 gal)	19	19	19	19	19	19	19	19	19
500,001-1,000,000	Total Capital Cost (K$)	36000	36000	36000	36000	36000	36000	36000	36000	36000
210.0	O&M Cost (K$/year)	1200	1200	1200	1200	1200	1200	1200	1200	1200
120.0	Total Production Cost (cents/1,000 gal)	12	12	12	12	12	12	12	12	12
>1,000,000	Total Capital Cost (K$)	63000	63000	63000	63000	63000	63000	63000	63000	63000
430.0	O&M Cost (K$/year)	2600	2600	2600	2600	2600	2600	2600	2600	2600
270.0	Total Production Cost (cents/1,000 gal)	10	10	10	10	10	10	10	10	10

GAC Adsorption -- Costs for Removing===> Aldicarb

	Influent (ug/L)	50.00			100.00			500.00		
Population Range Design Flow (MGD)	Effluent (ug/L)	1.30	10.00	20.00	1.30	10.00	20.00	1.30	10.00	20.00
Average Daily Flow (MGD)	Percent Removed	97.40	80.00	60.00	98.70	90.00	80.00	99.74	98.00	96.00
25-100	Total Capital Cost (K$)	125	125	125	125	125	125	125	125	125
0.024	O&M Cost (K$/year)	4	4	4	4	4	4	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	910	910	910	930	930	930	930	930	930
101-500	Total Capital Cost (K$)	190	190	190	190	190	190	190	190	190
0.087	O&M Cost (K$/year)	5	5	5	7	7	7	7	7	7
0.024	Total Production Cost (cents/1,000 gal)	310	310	310	330	330	330	330	330	330
501-1,000	Total Capital Cost (K$)	300	300	300	300	300	300	300	300	300
0.27	O&M Cost (K$/year)	8	8	8	13	13	13	13	13	13
0.086	Total Production Cost (cents/1,000 gal)	140	140	140	150	150	150	150	150	150
1,001-3,300	Total Capital Cost (K$)	480	480	480	480	480	480	480	480	480
0.65	O&M Cost (K$/year)	14	14	14	27	27	27	27	27	27
0.23	Total Production Cost (cents/1,000 gal)	80	80	80	100	100	100	100	100	100
3,301-10,000	Total Capital Cost (K$)	800	800	800	800	800	800	800	800	800
1.8	O&M Cost (K$/year)	30	30	30	70	70	70	70	70	70
0.7	Total Production Cost (cents/1,000 gal)	49	49	49	64	64	64	64	64	64
10,001-25,000	Total Capital Cost (K$)	1700	1700	1700	1700	1700	1700	1700	1700	1700
4.8	O&M Cost (K$/year)	70	70	70	190	190	190	190	190	190
2.1	Total Production Cost (cents/1,000 gal)	36	36	36	51	51	51	51	51	51
25,001-50,000	Total Capital Cost (K$)	3300	3300	3300	3300	3300	3300	3300	3300	3300
11.0	O&M Cost (K$/year)	130	130	130	400	400	400	400	400	400
5.0	Total Production Cost (cents/1,000 gal)	29	29	29	44	44	44	44	44	44
50,001-75,000	Total Capital Cost (K$)	5100	5100	5100	7500	7500	7500	7500	7500	7500
18.0	O&M Cost (K$/year)	200	200	200	300	300	300	300	300	300
8.8	Total Production Cost (cents/1,000 gal)	25	25	25	37	37	37	37	37	37
75,001-100,000	Total Capital Cost (K$)	6500	6500	6500	9400	9400	9400	9400	9400	9400
26.0	O&M Cost (K$/year)	300	300	300	400	400	400	400	400	400
13.0	Total Production Cost (cents/1,000 gal)	23	23	23	32	32	32	32	32	32
100,001-500,000	Total Capital Cost (K$)	13000	13000	13000	14000	14000	14000	14000	14000	14000
51.0	O&M Cost (K$/year)	400	400	400	700	700	700	700	700	700
27.0	Total Production Cost (cents/1,000 gal)	19	19	19	25	25	25	25	25	25
500,001-1,000,000	Total Capital Cost (K$)	36000	36000	36000	39000	39000	39000	39000	39000	39000
210.0	O&M Cost (K$/year)	1200	1200	1200	2600	2600	2600	2600	2600	2600
120.0	Total Production Cost (cents/1,000 gal)	12	12	12	16	16	16	16	16	16
>1,000,000	Total Capital Cost (K$)	63000	63000	63000	67000	67000	67000	67000	67000	67000
430.0	O&M Cost (K$/year)	2600	2600	2600	5400	5400	5400	5400	5400	5400
270.0	Total Production Cost (cents/1,000 gal)	10	10	10	14	14	14	14	14	14

GAC Adsorption -- Costs for Removing===> Atrazine

Population Range Design Flow (MGD) Average Daily Flow (MGD)	Influent (ug/L)	5.00			50.00			100.00		
	Effluent (ug/L)	1.00	3.00	5.00	1.00	3.00	5.00	1.00	3.00	5.00
	Percent Removed	80.00	40.00	0.00	98.00	94.00	90.00	99.00	97.00	95.00
25-100	Total Capital Cost (K$)	125	125	---	125	125	125	125	125	125
0.024	O&M Cost (K$/year)	4	4	---	4	4	4	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	910	910	---	910	910	910	910	910	910
101-500	Total Capital Cost (K$)	190	190	---	190	190	190	190	190	190
0.087	O&M Cost (K$/year)	5	5	---	5	5	5	5	5	5
0.024	Total Production Cost (cents/1,000 gal)	310	310	---	310	310	310	310	310	310
501-1,000	Total Capital Cost (K$)	300	300	---	300	300	300	300	300	300
0.27	O&M Cost (K$/year)	8	8	---	8	8	8	8	8	8
0.086	Total Production Cost (cents/1,000 gal)	140	140	---	140	140	140	140	140	140
1,001-3,300	Total Capital Cost (K$)	480	480	---	480	480	480	480	480	480
0.65	O&M Cost (K$/year)	14	14	---	14	14	14	14	14	14
0.23	Total Production Cost (cents/1,000 gal)	80	80	---	80	80	80	80	80	80
3,301-10,000	Total Capital Cost (K$)	800	800	---	800	800	800	800	800	800
1.8	O&M Cost (K$/year)	30	30	---	30	30	30	30	30	30
0.7	Total Production Cost (cents/1,000 gal)	49	49	---	49	49	49	49	49	49
10,001-25,000	Total Capital Cost (K$)	1700	1700	---	1700	1700	1700	1700	1700	1700
4.8	O&M Cost (K$/year)	70	70	---	70	70	70	70	70	70
2.1	Total Production Cost (cents/1,000 gal)	36	36	---	36	36	36	36	36	36
25,001-50,000	Total Capital Cost (K$)	3300	3300	---	3300	3300	3300	3300	3300	3300
11.0	O&M Cost (K$/year)	130	130	---	130	130	130	130	130	130
5.0	Total Production Cost (cents/1,000 gal)	29	29	---	29	29	29	29	29	29
50,001-75,000	Total Capital Cost (K$)	5100	5100	---	5100	5100	5100	5100	5100	5100
18.0	O&M Cost (K$/year)	200	200	---	200	200	200	200	200	200
8.8	Total Production Cost (cents/1,000 gal)	25	25	---	25	25	25	25	25	25
75,001-100,000	Total Capital Cost (K$)	6500	6500	---	6500	6500	6500	6500	6500	6500
26.0	O&M Cost (K$/year)	300	300	---	300	300	300	300	300	300
13.0	Total Production Cost (cents/1,000 gal)	23	23	---	23	23	23	23	23	23
100,001-500,000	Total Capital Cost (K$)	13000	13000	---	13000	13000	13000	13000	13000	13000
51.0	O&M Cost (K$/year)	400	400	---	400	400	400	400	400	400
27.0	Total Production Cost (cents/1,000 gal)	19	19	---	19	19	19	19	19	19
500,001-1,000,000	Total Capital Cost (K$)	36000	36000	---	36000	36000	36000	36000	36000	36000
210.0	O&M Cost (K$/year)	1200	1200	---	1200	1200	1200	1200	1200	1200
120.0	Total Production Cost (cents/1,000 gal)	12	12	---	12	12	12	12	12	12
>1,000,000	Total Capital Cost (K$)	63000	63000	---	63000	63000	63000	63000	63000	63000
430.0	O&M Cost (K$/year)	2600	2600	---	2600	2600	2600	2600	2600	2600
270.0	Total Production Cost (cents/1,000 gal)	10	10	---	10	10	10	10	10	10

GAC Adsorption -- Costs for Removing===> Carbofuran

	Influent (ug/L)	20.00			50.00			100.00		
Population Range Design Flow (MGD)	Effluent (ug/L)	5.00	40.00	50.00	5.00	40.00	50.00	5.00	40.00	50.00
Average Daily Flow (MGD)	Percent Removed	75.00	---	---	90.00	20.00	0.00	95.00	60.00	50.00
25-100	Total Capital Cost (K$)	125	---	---	125	125	---	125	125	125
0.024	O&M Cost (K$/year)	4	---	---	4	4	---	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	910	---	---	910	910	---	910	910	910
101-500	Total Capital Cost (K$)	190	---	---	190	190	---	190	190	190
0.087	O&M Cost (K$/year)	5	---	---	5	5	---	5	5	5
0.024	Total Production Cost (cents/1,000 gal)	310	---	---	310	310	---	310	310	310
501-1,000	Total Capital Cost (K$)	300	---	---	300	300	---	300	300	300
0.27	O&M Cost (K$/year)	8	---	---	8	8	---	8	8	8
0.086	Total Production Cost (cents/1,000 gal)	140	---	---	140	140	---	140	140	140
1,001-3,300	Total Capital Cost (K$)	480	---	---	480	480	---	480	480	480
0.65	O&M Cost (K$/year)	14	---	---	14	14	---	14	14	14
0.23	Total Production Cost (cents/1,000 gal)	80	---	---	80	80	---	80	80	80
3,301-10,000	Total Capital Cost (K$)	800	---	---	800	800	---	800	800	800
1.8	O&M Cost (K$/year)	30	---	---	30	30	---	30	30	30
0.7	Total Production Cost (cents/1,000 gal)	49	---	---	49	49	---	49	49	49
10,001-25,000	Total Capital Cost (K$)	1700	---	---	1700	1700	---	1700	1700	1700
4.8	O&M Cost (K$/year)	70	---	---	70	70	---	70	70	70
2.1	Total Production Cost (cents/1,000 gal)	36	---	---	36	36	---	36	36	36
25,001-50,000	Total Capital Cost (K$)	3300	---	---	3300	3300	---	3300	3300	3300
11.0	O&M Cost (K$/year)	130	---	---	130	130	---	130	130	130
5.0	Total Production Cost (cents/1,000 gal)	29	---	---	29	29	---	29	29	29
50,001-75,000	Total Capital Cost (K$)	5100	---	---	5100	5100	---	5100	5100	5100
18.0	O&M Cost (K$/year)	200	---	---	200	200	---	200	200	200
8.8	Total Production Cost (cents/1,000 gal)	25	---	---	25	25	---	25	25	25
75,001-100,000	Total Capital Cost (K$)	6500	---	---	6500	6500	---	6500	6500	6500
26.0	O&M Cost (K$/year)	300	---	---	300	300	---	300	300	300
13.0	Total Production Cost (cents/1,000 gal)	23	---	---	23	23	---	23	23	23
100,001-500,000	Total Capital Cost (K$)	13000	---	---	13000	13000	---	13000	13000	13000
51.0	O&M Cost (K$/year)	400	---	---	400	400	---	400	400	400
27.0	Total Production Cost (cents/1,000 gal)	19	---	---	19	19	---	19	19	19
500,001-1,000,000	Total Capital Cost (K$)	36000	---	---	36000	36000	---	36000	36000	36000
210.0	O&M Cost (K$/year)	1200	---	---	1200	1200	---	1200	1200	1200
120.0	Total Production Cost (cents/1,000 gal)	12	---	---	12	12	---	12	12	12
>1,000,000	Total Capital Cost (K$)	63000	---	---	63000	63000	---	63000	63000	63000
430.0	O&M Cost (K$/year)	2600	---	---	2600	2600	---	2600	2600	2600
270.0	Total Production Cost (cents/1,000 gal)	10	---	---	10	10	---	10	10	10

GAC Adsorption -- Costs for Removing===> Chlordane

Population Range Design Flow (MGD) Average Daily Flow (MGD)	Influent (ug/L)	5.00			10.00			50.00		
	Effluent (ug/L)	0.50	2.00	5.00	0.50	2.00	5.00	0.50	2.00	5.00
	Percent Removed	90.00	60.00	0.00	95.00	80.00	50.00	99.00	96.00	90.00
25-100	Total Capital Cost (K$)	125	125	---	125	125	125	125	125	125
0.024	O&M Cost (K$/year)	4	4	---	4	4	4	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	910	910	---	910	910	910	910	910	910
101-500	Total Capital Cost (K$)	190	190	---	190	190	190	190	190	190
0.087	O&M Cost (K$/year)	5	5	---	5	5	5	5	5	5
0.024	Total Production Cost (cents/1,000 gal)	310	310	---	310	310	310	310	310	310
501-1,000	Total Capital Cost (K$)	300	300	---	300	300	300	300	300	300
0.27	O&M Cost (K$/year)	8	8	---	8	8	8	8	8	8
0.086	Total Production Cost (cents/1,000 gal)	140	140	---	140	140	140	140	140	140
1,001-3,300	Total Capital Cost (K$)	480	480	---	480	480	480	480	480	480
0.65	O&M Cost (K$/year)	14	14	---	14	14	14	14	14	14
0.23	Total Production Cost (cents/1,000 gal)	80	80	---	80	80	80	80	80	80
3,301-10,000	Total Capital Cost (K$)	800	800	---	800	800	800	800	800	800
1.8	O&M Cost (K$/year)	30	30	---	30	30	30	30	30	30
0.7	Total Production Cost (cents/1,000 gal)	49	49	---	49	49	49	49	49	49
10,001-25,000	Total Capital Cost (K$)	1700	1700	---	1700	1700	1700	1700	1700	1700
4.8	O&M Cost (K$/year)	70	70	---	70	70	70	70	70	70
2.1	Total Production Cost (cents/1,000 gal)	36	36	---	36	36	36	36	36	36
25,001-50,000	Total Capital Cost (K$)	3300	3300	---	3300	3300	3300	3300	3300	3300
11.0	O&M Cost (K$/year)	130	130	---	130	130	130	130	130	130
5.0	Total Production Cost (cents/1,000 gal)	29	29	---	29	29	29	29	29	29
50,001-75,000	Total Capital Cost (K$)	5100	5100	---	5100	5100	5100	5100	5100	5100
18.0	O&M Cost (K$/year)	200	200	---	200	200	200	200	200	200
8.8	Total Production Cost (cents/1,000 gal)	25	25	---	25	25	25	25	25	25
75,001-100,000	Total Capital Cost (K$)	6500	6500	---	6500	6500	6500	6500	6500	6500
26.0	O&M Cost (K$/year)	300	300	---	300	300	300	300	300	300
13.0	Total Production Cost (cents/1,000 gal)	23	23	---	23	23	23	23	23	23
100,001-500,000	Total Capital Cost (K$)	13000	13000	---	13000	13000	13000	13000	13000	13000
51.0	O&M Cost (K$/year)	400	400	---	400	400	400	400	400	400
27.0	Total Production Cost (cents/1,000 gal)	19	19	---	19	19	19	19	19	19
500,001-1,000,000	Total Capital Cost (K$)	36000	36000	---	36000	36000	36000	36000	36000	36000
210.0	O&M Cost (K$/year)	1200	1200	---	1200	1200	1200	1200	1200	1200
120.0	Total Production Cost (cents/1,000 gal)	12	12	---	12	12	12	12	12	12
>1,000,000	Total Capital Cost (K$)	63000	63000	---	63000	63000	63000	63000	63000	63000
430.0	O&M Cost (K$/year)	2600	2600	---	2600	2600	2600	2600	2600	2600
270.0	Total Production Cost (cents/1,000 gal)	10	10	---	10	10	10	10	10	10

GAC Adsorption -- Costs for Removing===> cis-1,2-Dichloroethylene

Population Range Design Flow (MGD) Average Daily Flow (MGD)	Influent (ug/L)	50.00			100.00			200.00		
	Effluent (ug/L)	5.00	70.00	100.00	5.00	70.00	100.00	5.00	70.00	100.00
	Percent Removed	90.00	---	---	95.00	30.00	0.00	97.50	65.00	50.00
25-100	Total Capital Cost (K$)	125	---	---	125	125	---	125	125	125
0.024	O&M Cost (K$/year)	5	---	---	5	5	---	5	5	5
0.0056	Total Production Cost (cents/1,000 gal)	950	---	---	950	950	---	950	950	950
101-500	Total Capital Cost (K$)	190	---	---	190	190	---	190	190	190
0.087	O&M Cost (K$/year)	9	---	---	9	9	---	9	9	9
0.024	Total Production Cost (cents/1,000 gal)	350	---	---	350	350	---	350	350	350
501-1,000	Total Capital Cost (K$)	300	---	---	300	300	---	300	300	300
0.27	O&M Cost (K$/year)	21	---	---	21	21	---	21	21	21
0.086	Total Production Cost (cents/1,000 gal)	180	---	---	180	180	---	180	180	180
1,001-3,300	Total Capital Cost (K$)	480	---	---	480	480	---	480	480	480
0.65	O&M Cost (K$/year)	48	---	---	48	48	---	48	48	48
0.23	Total Production Cost (cents/1,000 gal)	120	---	---	120	120	---	120	120	120
3,301-10,000	Total Capital Cost (K$)	800	---	---	800	800	---	800	800	800
1.8	O&M Cost (K$/year)	130	---	---	130	130	---	130	130	130
0.7	Total Production Cost (cents/1,000 gal)	89	---	---	89	89	---	89	89	89
10,001-25,000	Total Capital Cost (K$)	1700	---	---	1700	1700	---	1700	1700	1700
4.8	O&M Cost (K$/year)	380	---	---	380	380	---	380	380	380
2.1	Total Production Cost (cents/1,000 gal)	76	---	---	76	76	---	76	76	76
25,001-50,000	Total Capital Cost (K$)	6000	---	---	6000	6000	---	6000	6000	6000
11.0	O&M Cost (K$/year)	340	---	---	340	340	---	340	340	340
5.0	Total Production Cost (cents/1,000 gal)	58	---	---	58	58	---	58	58	58
50,001-75,000	Total Capital Cost (K$)	8500	---	---	8500	8500	---	8500	8500	8500
18.0	O&M Cost (K$/year)	500	---	---	500	500	---	500	500	500
8.8	Total Production Cost (cents/1,000 gal)	47	---	---	47	47	---	47	47	47
75,001-100,000	Total Capital Cost (K$)	10000	---	---	10000	10000	---	10000	10000	10000
26.0	O&M Cost (K$/year)	700	---	---	700	700	---	700	700	700
13.0	Total Production Cost (cents/1,000 gal)	41	---	---	41	41	---	41	41	41
100,001-500,000	Total Capital Cost (K$)	16000	---	---	16000	16000	---	16000	16000	16000
51.0	O&M Cost (K$/year)	1300	---	---	1300	1300	---	1300	1300	1300
27.0	Total Production Cost (cents/1,000 gal)	32	---	---	32	32	---	32	32	32
500,001-1,000,000	Total Capital Cost (K$)	42000	---	---	42000	42000	---	42000	42000	42000
210.0	O&M Cost (K$/year)	4700	---	---	4700	4700	---	4700	4700	4700
120.0	Total Production Cost (cents/1,000 gal)	22	---	---	22	22	---	22	22	22
>1,000,000	Total Capital Cost (K$)	71000	---	---	71000	71000	---	71000	71000	71000
430.0	O&M Cost (K$/year)	9900	---	---	9900	9900	---	9900	9900	9900
270.0	Total Production Cost (cents/1,000 gal)	19	---	---	19	19	---	19	19	19

GAC Adsorption -- Costs for Removing===> DBCP

	Influent (ug/L)	2.00			5.00			20.00		
Population Range	Effluent (ug/L)	0.10	0.20	1.00	0.10	0.20	1.00	0.10	0.20	1.00
Design Flow (MGD)										
Average Daily Flow (MGD)	Percent Removed	95.00	90.00	50.00	98.00	96.00	80.00	99.50	99.00	95.00
25-100	Total Capital Cost (K$)	125	125	125	125	125	125	125	125	125
0.024	O&M Cost (K$/year)	4	4	4	4	4	4	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	910	910	910	910	910	910	910	910	910
101-500	Total Capital Cost (K$)	190	190	190	190	190	190	190	190	190
0.087	O&M Cost (K$/year)	5	5	5	5	5	5	5	5	5
0.024	Total Production Cost (cents/1,000 gal)	310	310	310	310	310	310	310	310	310
501-1,000	Total Capital Cost (K$)	300	300	300	300	300	300	300	300	300
0.27	O&M Cost (K$/year)	8	8	8	8	8	8	8	8	8
0.086	Total Production Cost (cents/1,000 gal)	140	140	140	140	140	140	140	140	140
1,001-3,300	Total Capital Cost (K$)	480	480	480	480	480	480	480	480	480
0.65	O&M Cost (K$/year)	14	14	14	14	14	14	14	14	14
0.23	Total Production Cost (cents/1,000 gal)	80	80	80	80	80	80	80	80	80
3,301-10,000	Total Capital Cost (K$)	800	800	800	800	800	800	800	800	800
1.8	O&M Cost (K$/year)	30	30	30	30	30	30	30	30	30
0.7	Total Production Cost (cents/1,000 gal)	49	49	49	49	49	49	49	49	49
10,001-25,000	Total Capital Cost (K$)	1700	1700	1700	1700	1700	1700	1700	1700	1700
4.8	O&M Cost (K$/year)	70	70	70	70	70	70	70	70	70
2.1	Total Production Cost (cents/1,000 gal)	36	36	36	36	36	36	36	36	36
25,001-50,000	Total Capital Cost (K$)	3300	3300	3300	3300	3300	3300	3300	3300	3300
11.0	O&M Cost (K$/year)	130	130	130	130	130	130	130	130	130
5.0	Total Production Cost (cents/1,000 gal)	29	29	29	29	29	29	29	29	29
50,001-75,000	Total Capital Cost (K$)	5100	5100	5100	5100	5100	5100	5100	5100	5100
18.0	O&M Cost (K$/year)	200	200	200	200	200	200	200	200	200
8.8	Total Production Cost (cents/1,000 gal)	25	25	25	25	25	25	25	25	25
75,001-100,000	Total Capital Cost (K$)	6500	6500	6500	6500	6500	6500	6500	6500	6500
26.0	O&M Cost (K$/year)	300	300	300	300	300	300	300	300	300
13.0	Total Production Cost (cents/1,000 gal)	23	23	23	23	23	23	23	23	23
100,001-500,000	Total Capital Cost (K$)	13000	13000	13000	13000	13000	13000	13000	13000	13000
51.0	O&M Cost (K$/year)	400	400	400	400	400	400	400	400	400
27.0	Total Production Cost (cents/1,000 gal)	19	19	19	19	19	19	19	19	19
500,001-1,000,000	Total Capital Cost (K$)	36000	36000	36000	36000	36000	36000	36000	36000	36000
210.0	O&M Cost (K$/year)	1200	1200	1200	1200	1200	1200	1200	1200	1200
120.0	Total Production Cost (cents/1,000 gal)	12	12	12	12	12	12	12	12	12
>1,000,000	Total Capital Cost (K$)	63000	63000	63000	63000	63000	63000	63000	63000	63000
430.0	O&M Cost (K$/year)	2600	2600	2600	2600	2600	2600	2600	2600	2600
270.0	Total Production Cost (cents/1,000 gal)	10	10	10	10	10	10	10	10	10

GAC Adsorption -- Costs for Removing===> o-Dichlorobenzene

Population Range Design Flow (MGD) Average Daily Flow (MGD)	Influent (ug/L)	100.00			700.00			1000.00		
	Effluent (ug/L)	50.00	600.00	800.00	50.00	600.00	800.00	50.00	600.00	800.00
	Percent Removed	50.00	---	---	92.86	14.29	---	95.00	40.00	20.00
25-100	Total Capital Cost (K$)	125	---	---	125	125	---	125	125	125
0.024	O&M Cost (K$/year)	4	---	---	4	4	---	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	910	---	---	930	930	---	930	930	930
101-500	Total Capital Cost (K$)	190	---	---	190	190	---	190	190	190
0.087	O&M Cost (K$/year)	5	---	---	7	7	---	7	7	7
0.024	Total Production Cost (cents/1,000 gal)	310	---	---	330	330	---	330	330	330
501-1,000	Total Capital Cost (K$)	300	---	---	300	300	---	300	300	300
0.27	O&M Cost (K$/year)	8	---	---	13	13	---	13	13	13
0.086	Total Production Cost (cents/1,000 gal)	140	---	---	150	150	---	150	150	150
1,001-3,300	Total Capital Cost (K$)	480	---	---	480	480	---	480	480	480
0.65	O&M Cost (K$/year)	14	---	---	27	27	---	27	27	27
0.23	Total Production Cost (cents/1,000 gal)	80	---	---	100	100	---	100	100	100
3,301-10,000	Total Capital Cost (K$)	800	---	---	800	800	---	800	800	800
1.8	O&M Cost (K$/year)	30	---	---	70	70	---	70	70	70
0.7	Total Production Cost (cents/1,000 gal)	49	---	---	64	64	---	64	64	64
10,001-25,000	Total Capital Cost (K$)	1700	---	---	1700	1700	---	1700	1700	1700
4.8	O&M Cost (K$/year)	70	---	---	190	190	---	190	190	190
2.1	Total Production Cost (cents/1,000 gal)	36	---	---	51	51	---	51	51	51
25,001-50,000	Total Capital Cost (K$)	3300	---	---	3300	3300	---	3300	3300	3300
11.0	O&M Cost (K$/year)	130	---	---	400	400	---	400	400	400
5.0	Total Production Cost (cents/1,000 gal)	29	---	---	44	44	---	44	44	44
50,001-75,000	Total Capital Cost (K$)	5100	---	---	7500	7500	---	7500	7500	7500
18.0	O&M Cost (K$/year)	200	---	---	300	300	---	300	300	300
8.8	Total Production Cost (cents/1,000 gal)	25	---	---	37	37	---	37	37	37
75,001-100,000	Total Capital Cost (K$)	6500	---	---	9400	9400	---	9400	9400	9400
26.0	O&M Cost (K$/year)	300	---	---	400	400	---	400	400	400
13.0	Total Production Cost (cents/1,000 gal)	23	---	---	32	32	---	32	32	32
100,001-500,000	Total Capital Cost (K$)	13000	---	---	14000	14000	---	14000	14000	14000
51.0	O&M Cost (K$/year)	400	---	---	700	700	---	700	700	700
27.0	Total Production Cost (cents/1,000 gal)	19	---	---	25	25	---	25	25	25
500,001-1,000,000	Total Capital Cost (K$)	36000	---	---	39000	39000	---	39000	39000	39000
210.0	O&M Cost (K$/year)	1200	---	---	2600	2600	---	2600	2600	2600
120.0	Total Production Cost (cents/1,000 gal)	12	---	---	16	16	---	16	16	16
>1,000,000	Total Capital Cost (K$)	63000	---	---	67000	67000	---	67000	67000	67000
430.0	O&M Cost (K$/year)	2600	---	---	5400	5400	---	5400	5400	5400
270.0	Total Production Cost (cents/1,000 gal)	10	---	---	14	14	---	14	14	14

GAC Adsorption -- Costs for Removing===> 1,2-Dichloropropane

	Influent (ug/L)	10.00			50.00			100.00		
Population Range Design Flow (MGD)	Effluent (ug/L)	2.00	5.00	10.00	2.00	5.00	10.00	2.00	5.00	10.00
Average Daily Flow (MGD)	Percent Removed	80.00	50.00	0.00	96.00	90.00	80.00	98.00	95.00	90.00
25-100	Total Capital Cost (K$)	125	125	---	125	125	125	125	125	125
0.024	O&M Cost (K$/year)	4	4	---	4	4	4	5	5	5
0.0056	Total Production Cost (cents/1,000 gal)	930	930	---	930	930	930	950	950	950
101-500	Total Capital Cost (K$)	190	190	---	190	190	190	190	190	190
0.087	O&M Cost (K$/year)	7	7	---	7	7	7	9	9	9
0.024	Total Production Cost (cents/1,000 gal)	330	330	---	330	330	330	350	350	350
501-1,000	Total Capital Cost (K$)	300	300	---	300	300	300	300	300	300
0.27	O&M Cost (K$/year)	13	13	---	13	13	13	21	21	21
0.086	Total Production Cost (cents/1,000 gal)	150	150	---	150	150	150	180	180	180
1,001-3,300	Total Capital Cost (K$)	480	480	---	480	480	480	480	480	480
0.65	O&M Cost (K$/year)	27	27	---	27	27	27	48	48	48
0.23	Total Production Cost (cents/1,000 gal)	100	100	---	100	100	100	120	120	120
3,301-10,000	Total Capital Cost (K$)	800	800	---	800	800	800	800	800	800
1.8	O&M Cost (K$/year)	70	70	---	70	70	70	130	130	130
0.7	Total Production Cost (cents/1,000 gal)	64	64	---	64	64	64	89	89	89
10,001-25,000	Total Capital Cost (K$)	1700	1700	---	1700	1700	1700	1700	1700	1700
4.8	O&M Cost (K$/year)	190	190	---	190	190	190	380	380	380
2.1	Total Production Cost (cents/1,000 gal)	51	51	---	51	51	51	76	76	76
25,001-50,000	Total Capital Cost (K$)	3300	3300	---	3300	3300	3300	6000	6000	6000
11.0	O&M Cost (K$/year)	400	400	---	400	400	400	340	340	340
5.0	Total Production Cost (cents/1,000 gal)	44	44	---	44	44	44	58	58	58
50,001-75,000	Total Capital Cost (K$)	7500	7500	---	7500	7500	7500	8500	8500	8500
18.0	O&M Cost (K$/year)	300	300	---	300	300	300	500	500	500
8.8	Total Production Cost (cents/1,000 gal)	37	37	---	37	37	37	47	47	47
75,001-100,000	Total Capital Cost (K$)	9400	9400	---	9400	9400	9400	10000	10000	10000
26.0	O&M Cost (K$/year)	400	400	---	400	400	400	700	700	700
13.0	Total Production Cost (cents/1,000 gal)	32	32	---	32	32	32	41	41	41
100,001-500,000	Total Capital Cost (K$)	14000	14000	---	14000	14000	14000	16000	16000	16000
51.0	O&M Cost (K$/year)	700	700	---	700	700	700	1300	1300	1300
27.0	Total Production Cost (cents/1,000 gal)	25	25	---	25	25	25	32	32	32
500,001-1,000,000	Total Capital Cost (K$)	39000	39000	---	39000	39000	39000	42000	42000	42000
210.0	O&M Cost (K$/year)	2600	2600	---	2600	2600	2600	4700	4700	4700
120.0	Total Production Cost (cents/1,000 gal)	16	16	---	16	16	16	22	22	22
>1,000,000	Total Capital Cost (K$)	67000	67000	---	67000	67000	67000	71000	71000	71000
430.0	O&M Cost (K$/year)	5400	5400	---	5400	5400	5400	9900	9900	9900
270.0	Total Production Cost (cents/1,000 gal)	14	14	---	14	14	14	19	19	19

GAC Adsorption -- Costs for Removing===> 2,4-D

	Influent (ug/L)	50.00			100.00			500.00		
Population Range Design Flow (MGD) Average Daily Flow (MGD)	Effluent (ug/L)	5.00	70.00	100.00	5.00	70.00	100.00	5.00	70.00	100.00
	Percent Removed	90.00	---	---	95.00	30.00	0.00	99.00	86.00	80.00
25-100	Total Capital Cost (K$)	125	---	---	125	125	---	125	125	125
0.024	O&M Cost (K$/year)	4	---	---	4	4	---	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	910	---	---	930	930	---	930	930	930
101-500	Total Capital Cost (K$)	190	---	---	190	190	---	190	190	190
0.087	O&M Cost (K$/year)	5	---	---	7	7	---	7	7	7
0.024	Total Production Cost (cents/1,000 gal)	310	---	---	330	330	---	330	330	330
501-1,000	Total Capital Cost (K$)	300	---	---	300	300	---	300	300	300
0.27	O&M Cost (K$/year)	8	---	---	13	13	---	13	13	13
0.086	Total Production Cost (cents/1,000 gal)	140	---	---	150	150	---	150	150	150
1,001-3,300	Total Capital Cost (K$)	480	---	---	480	480	---	480	480	480
0.65	O&M Cost (K$/year)	14	---	---	27	27	---	27	27	27
0.23	Total Production Cost (cents/1,000 gal)	80	---	---	100	100	---	100	100	100
3,301-10,000	Total Capital Cost (K$)	800	---	---	800	800	---	800	800	800
1.8	O&M Cost (K$/year)	30	---	---	70	70	---	70	70	70
0.7	Total Production Cost (cents/1,000 gal)	49	---	---	64	64	---	64	64	64
10,001-25,000	Total Capital Cost (K$)	1700	---	---	1700	1700	---	1700	1700	1700
4.8	O&M Cost (K$/year)	70	---	---	190	190	---	190	190	190
2.1	Total Production Cost (cents/1,000 gal)	36	---	---	51	51	---	51	51	51
25,001-50,000	Total Capital Cost (K$)	3300	---	---	3300	3300	---	3300	3300	3300
11.0	O&M Cost (K$/year)	130	---	---	400	400	---	400	400	400
5.0	Total Production Cost (cents/1,000 gal)	29	---	---	44	44	---	44	44	44
50,001-75,000	Total Capital Cost (K$)	5100	---	---	7500	7500	---	7500	7500	7500
18.0	O&M Cost (K$/year)	200	---	---	300	300	---	300	300	300
8.8	Total Production Cost (cents/1,000 gal)	25	---	---	37	37	---	37	37	37
75,001-100,000	Total Capital Cost (K$)	6500	---	---	9400	9400	---	9400	9400	9400
26.0	O&M Cost (K$/year)	300	---	---	400	400	---	400	400	400
13.0	Total Production Cost (cents/1,000 gal)	23	---	---	32	32	---	32	32	32
100,001-500,000	Total Capital Cost (K$)	13000	---	---	14000	14000	---	14000	14000	14000
51.0	O&M Cost (K$/year)	400	---	---	700	700	---	700	700	700
27.0	Total Production Cost (cents/1,000 gal)	19	---	---	25	25	---	25	25	25
500,001-1,000,000	Total Capital Cost (K$)	36000	---	---	39000	39000	---	39000	39000	39000
210.0	O&M Cost (K$/year)	1200	---	---	2600	2600	---	2600	2600	2600
120.0	Total Production Cost (cents/1,000 gal)	12	---	---	16	16	---	16	16	16
>1,000,000	Total Capital Cost (K$)	63000	---	---	67000	67000	---	67000	67000	67000
430.0	O&M Cost (K$/year)	2600	---	---	5400	5400	---	5400	5400	5400
270.0	Total Production Cost (cents/1,000 gal)	10	---	---	14	14	---	14	14	14

GAC Adsorption -- Costs for Removing===> Ethyl Benzene

Population Range Design Flow (MGD) Average Daily Flow (MGD)	Influent (ug/L)	100.00			700.00			1000.00		
	Effluent (ug/L)	50.00	700.00	800.00	50.00	700.00	800.00	50.00	700.00	800.00
	Percent Removed	50.00	---	---	92.86	0.00	---	95.00	30.00	20.00
25-100	Total Capital Cost (K$)	125	---	---	125	---	---	125	125	125
0.024	O&M Cost (K$/year)	4	---	---	4	---	---	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	930	---	---	930	---	---	930	930	930
101-500	Total Capital Cost (K$)	190	---	---	190	---	---	190	190	190
0.087	O&M Cost (K$/year)	7	---	---	7	---	---	7	7	7
0.024	Total Production Cost (cents/1,000 gal)	330	---	---	330	---	---	330	330	330
501-1,000	Total Capital Cost (K$)	300	---	---	300	---	---	300	300	300
0.27	O&M Cost (K$/year)	13	---	---	13	---	---	13	13	13
0.086	Total Production Cost (cents/1,000 gal)	150	---	---	150	---	---	150	150	150
1,001-3,300	Total Capital Cost (K$)	480	---	---	480	---	---	480	480	480
0.65	O&M Cost (K$/year)	27	---	---	27	---	---	27	27	27
0.23	Total Production Cost (cents/1,000 gal)	100	---	---	100	---	---	100	100	100
3,301-10,000	Total Capital Cost (K$)	800	---	---	800	---	---	800	800	800
1.8	O&M Cost (K$/year)	70	---	---	70	---	---	70	70	70
0.7	Total Production Cost (cents/1,000 gal)	64	---	---	64	---	---	64	64	64
10,001-25,000	Total Capital Cost (K$)	1700	---	---	1700	---	---	1700	1700	1700
4.8	O&M Cost (K$/year)	190	---	---	190	---	---	190	190	190
2.1	Total Production Cost (cents/1,000 gal)	51	---	---	51	---	---	51	51	51
25,001-50,000	Total Capital Cost (K$)	3300	---	---	3300	---	---	3300	3300	3300
11.0	O&M Cost (K$/year)	400	---	---	400	---	---	400	400	400
5.0	Total Production Cost (cents/1,000 gal)	44	---	---	44	---	---	44	44	44
50,001-75,000	Total Capital Cost (K$)	7500	---	---	7500	---	---	7500	7500	7500
18.0	O&M Cost (K$/year)	300	---	---	300	---	---	300	300	300
8.8	Total Production Cost (cents/1,000 gal)	37	---	---	37	---	---	37	37	37
75,001-100,000	Total Capital Cost (K$)	9400	---	---	9400	---	---	9400	9400	9400
26.0	O&M Cost (K$/year)	400	---	---	400	---	---	400	400	400
13.0	Total Production Cost (cents/1,000 gal)	32	---	---	32	---	---	32	32	32
100,001-500,000	Total Capital Cost (K$)	14000	---	---	14000	---	---	14000	14000	14000
51.0	O&M Cost (K$/year)	700	---	---	700	---	---	700	700	700
27.0	Total Production Cost (cents/1,000 gal)	25	---	---	25	---	---	25	25	25
500,001-1,000,000	Total Capital Cost (K$)	39000	---	---	39000	---	---	39000	39000	39000
210.0	O&M Cost (K$/year)	2600	---	---	2600	---	---	2600	2600	2600
120.0	Total Production Cost (cents/1,000 gal)	16	---	---	16	---	---	16	16	16
>1,000,000	Total Capital Cost (K$)	67000	---	---	67000	---	---	67000	67000	67000
430.0	O&M Cost (K$/year)	5400	---	---	5400	---	---	5400	5400	5400
270.0	Total Production Cost (cents/1,000 gal)	14	---	---	14	---	---	14	14	14

GAC Adsorption -- Costs for Removing===> EDB

Population Range Design Flow (MGD) Average Daily Flow (MGD)	Influent (ug/L)	0.50			10.00			50.00		
	Effluent (ug/L)	0.01	0.05	1.00	0.01	0.05	1.00	0.01	0.05	1.00
	Percent Removed	98.00	90.00	---	99.90	99.50	90.00	99.98	99.90	98.00
25-100	Total Capital Cost (K$)	125	125	---	125	125	125	125	125	125
0.024	O&M Cost (K$/year)	4	4	---	4	4	4	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	910	910	---	930	930	930	930	930	930
101-500	Total Capital Cost (K$)	190	190	---	190	190	190	190	190	190
0.087	O&M Cost (K$/year)	5	5	---	7	7	7	7	7	7
0.024	Total Production Cost (cents/1,000 gal)	310	310	---	330	330	330	330	330	330
501-1,000	Total Capital Cost (K$)	300	300	---	300	300	300	300	300	300
0.27	O&M Cost (K$/year)	8	8	---	13	13	13	13	13	13
0.086	Total Production Cost (cents/1,000 gal)	140	140	---	150	150	150	150	150	150
1,001-3,300	Total Capital Cost (K$)	480	480	---	480	480	480	480	480	480
0.65	O&M Cost (K$/year)	14	14	---	27	27	27	27	27	27
0.23	Total Production Cost (cents/1,000 gal)	80	80	---	100	100	100	100	100	100
3,301-10,000	Total Capital Cost (K$)	800	800	---	800	800	800	800	800	800
1.8	O&M Cost (K$/year)	30	30	---	70	70	70	70	70	70
0.7	Total Production Cost (cents/1,000 gal)	49	49	---	64	64	64	64	64	64
10,001-25,000	Total Capital Cost (K$)	1700	1700	---	1700	1700	1700	1700	1700	1700
4.8	O&M Cost (K$/year)	70	70	---	190	190	190	190	190	190
2.1	Total Production Cost (cents/1,000 gal)	36	36	---	51	51	51	51	51	51
25,001-50,000	Total Capital Cost (K$)	3300	3300	---	3300	3300	3300	3300	3300	3300
11.0	O&M Cost (K$/year)	130	130	---	400	400	400	400	400	400
5.0	Total Production Cost (cents/1,000 gal)	29	29	---	44	44	44	44	44	44
50,001-75,000	Total Capital Cost (K$)	5100	5100	---	7500	7500	7500	7500	7500	7500
18.0	O&M Cost (K$/year)	200	200	---	300	300	300	300	300	300
8.8	Total Production Cost (cents/1,000 gal)	25	25	---	37	37	37	37	37	37
75,001-100,000	Total Capital Cost (K$)	6500	6500	---	9400	9400	9400	9400	9400	9400
26.0	O&M Cost (K$/year)	300	300	---	400	400	400	400	400	400
13.0	Total Production Cost (cents/1,000 gal)	23	23	---	32	32	32	32	32	32
100,001-500,000	Total Capital Cost (K$)	13000	13000	---	14000	14000	14000	14000	14000	14000
51.0	O&M Cost (K$/year)	400	400	---	700	700	700	700	700	700
27.0	Total Production Cost (cents/1,000 gal)	19	19	---	25	25	25	25	25	25
500,001-1,000,000	Total Capital Cost (K$)	36000	36000	---	39000	39000	39000	39000	39000	39000
210.0	O&M Cost (K$/year)	1200	1200	---	2600	2600	2600	2600	2600	2600
120.0	Total Production Cost (cents/1,000 gal)	12	12	---	16	16	16	16	16	16
>1,000,000	Total Capital Cost (K$)	63000	63000	---	67000	67000	67000	67000	67000	67000
430.0	O&M Cost (K$/year)	2600	2600	---	5400	5400	5400	5400	5400	5400
270.0	Total Production Cost (cents/1,000 gal)	10	10	---	14	14	14	14	14	14

GAC Adsorption -- Costs for Removing===> Heptachlor

Population Range Design Flow (MGD) Average Daily Flow (MGD)	Influent (ug/L)	0.10			1.00			10.00		
	Effluent (ug/L)	0.03	0.40	1.00	0.03	0.40	1.00	0.03	0.40	1.00
	Percent Removed	70.00	---	---	97.00	60.00	0.00	99.70	96.00	90.00
25-100	Total Capital Cost (K$)	125	---	---	125	125	---	125	125	125
0.024	O&M Cost (K$/year)	4	---	---	4	4	---	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	910	---	---	910	910	---	910	910	910
101-500	Total Capital Cost (K$)	190	---	---	190	190	---	190	190	190
0.087	O&M Cost (K$/year)	5	---	---	5	5	---	5	5	5
0.024	Total Production Cost (cents/1,000 gal)	310	---	---	310	310	---	310	310	310
501-1,000	Total Capital Cost (K$)	300	---	---	300	300	---	300	300	300
0.27	O&M Cost (K$/year)	8	---	---	8	8	---	8	8	8
0.086	Total Production Cost (cents/1,000 gal)	140	---	---	140	140	---	140	140	140
1,001-3,300	Total Capital Cost (K$)	480	---	---	480	480	---	480	480	480
0.65	O&M Cost (K$/year)	14	---	---	14	14	---	14	14	14
0.23	Total Production Cost (cents/1,000 gal)	80	---	---	80	80	---	80	80	80
3,301-10,000	Total Capital Cost (K$)	800	---	---	800	800	---	800	800	800
1.8	O&M Cost (K$/year)	30	---	---	30	30	---	30	30	30
0.7	Total Production Cost (cents/1,000 gal)	49	---	---	49	49	---	49	49	49
10,001-25,000	Total Capital Cost (K$)	1700	---	---	1700	1700	---	1700	1700	1700
4.8	O&M Cost (K$/year)	70	---	---	70	70	---	70	70	70
2.1	Total Production Cost (cents/1,000 gal)	36	---	---	36	36	---	36	36	36
25,001-50,000	Total Capital Cost (K$)	3300	---	---	3300	3300	---	3300	3300	3300
11.0	O&M Cost (K$/year)	130	---	---	130	130	---	130	130	130
5.0	Total Production Cost (cents/1,000 gal)	29	---	---	29	29	---	29	29	29
50,001-75,000	Total Capital Cost (K$)	5100	---	---	5100	5100	---	5100	5100	5100
18.0	O&M Cost (K$/year)	200	---	---	200	200	---	200	200	200
8.8	Total Production Cost (cents/1,000 gal)	25	---	---	25	25	---	25	25	25
75,001-100,000	Total Capital Cost (K$)	6500	---	---	6500	6500	---	6500	6500	6500
26.0	O&M Cost (K$/year)	300	---	---	300	300	---	300	300	300
13.0	Total Production Cost (cents/1,000 gal)	23	---	---	23	23	---	23	23	23
100,001-500,000	Total Capital Cost (K$)	13000	---	---	13000	13000	---	13000	13000	13000
51.0	O&M Cost (K$/year)	400	---	---	400	400	---	400	400	400
27.0	Total Production Cost (cents/1,000 gal)	19	---	---	19	19	---	19	19	19
500,001-1,000,000	Total Capital Cost (K$)	36000	---	---	36000	36000	---	36000	36000	36000
210.0	O&M Cost (K$/year)	1200	---	---	1200	1200	---	1200	1200	1200
120.0	Total Production Cost (cents/1,000 gal)	12	---	---	12	12	---	12	12	12
>1,000,000	Total Capital Cost (K$)	63000	---	---	63000	63000	---	63000	63000	63000
430.0	O&M Cost (K$/year)	2600	---	---	2600	2600	---	2600	2600	2600
270.0	Total Production Cost (cents/1,000 gal)	10	---	---	10	10	---	10	10	10

GAC Adsorption -- Costs for Removing===> Heptachlor Epoxide

	Influent (ug/L)	0.10			1.00			10.00		
Population Range	Effluent (ug/L)	0.03	0.20	1.00	0.03	0.20	1.00	0.03	0.20	1.00
Design Flow (MGD)										
Average Daily Flow (MGD)	Percent Removed	70.00	---	---	97.00	80.00	0.00	99.70	98.00	90.00
25-100	Total Capital Cost (K$)	125	---	---	125	125	---	125	125	125
0.024	O&M Cost (K$/year)	4	---	---	4	4	---	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	910	---	---	910	910	---	910	910	910
101-500	Total Capital Cost (K$)	190	---	---	190	190	---	190	190	190
0.087	O&M Cost (K$/year)	5	---	---	5	5	---	5	5	5
0.024	Total Production Cost (cents/1,000 gal)	310	---	---	310	310	---	310	310	310
501-1,000	Total Capital Cost (K$)	300	---	---	300	300	---	300	300	300
0.27	O&M Cost (K$/year)	8	---	---	8	8	---	8	8	8
0.086	Total Production Cost (cents/1,000 gal)	140	---	---	140	140	---	140	140	140
1,001-3,300	Total Capital Cost (K$)	480	---	---	480	480	---	480	480	480
0.65	O&M Cost (K$/year)	14	---	---	14	14	---	14	14	14
0.23	Total Production Cost (cents/1,000 gal)	80	---	---	80	80	---	80	80	80
3,301-10,000	Total Capital Cost (K$)	800	---	---	800	800	---	800	800	800
1.8	O&M Cost (K$/year)	30	---	---	30	30	---	30	30	30
0.7	Total Production Cost (cents/1,000 gal)	49	---	---	49	49	---	49	49	49
10,001-25,000	Total Capital Cost (K$)	1700	---	---	1700	1700	---	1700	1700	1700
4.8	O&M Cost (K$/year)	70	---	---	70	70	---	70	70	70
2.1	Total Production Cost (cents/1,000 gal)	36	---	---	36	36	---	36	36	36
25,001-50,000	Total Capital Cost (K$)	3300	---	---	3300	3300	---	3300	3300	3300
11.0	O&M Cost (K$/year)	130	---	---	130	130	---	130	130	130
5.0	Total Production Cost (cents/1,000 gal)	29	---	---	29	29	---	29	29	29
50,001-75,000	Total Capital Cost (K$)	5100	---	---	5100	5100	---	5100	5100	5100
18.0	O&M Cost (K$/year)	200	---	---	200	200	---	200	200	200
8.8	Total Production Cost (cents/1,000 gal)	25	---	---	25	25	---	25	25	25
75,001-100,000	Total Capital Cost (K$)	6500	---	---	6500	6500	---	6500	6500	6500
26.0	O&M Cost (K$/year)	300	---	---	300	300	---	300	300	300
13.0	Total Production Cost (cents/1,000 gal)	23	---	---	23	23	---	23	23	23
100,001-500,000	Total Capital Cost (K$)	13000	---	---	13000	13000	---	13000	13000	13000
51.0	O&M Cost (K$/year)	400	---	---	400	400	---	400	400	400
27.0	Total Production Cost (cents/1,000 gal)	19	---	---	19	19	---	19	19	19
500,001-1,000,000	Total Capital Cost (K$)	36000	---	---	36000	36000	---	36000	36000	36000
210.0	O&M Cost (K$/year)	1200	---	---	1200	1200	---	1200	1200	1200
120.0	Total Production Cost (cents/1,000 gal)	12	---	---	12	12	---	12	12	12
>1,000,000	Total Capital Cost (K$)	63000	---	---	63000	63000	---	63000	63000	63000
430.0	O&M Cost (K$/year)	2600	---	---	2600	2600	---	2600	2600	2600
270.0	Total Production Cost (cents/1,000 gal)	10	---	---	10	10	---	10	10	10

GAC Adsorption -- Costs for Removing===> Lindane

Population Range Design Flow (MGD) Average Daily Flow (MGD)	Influent (ug/L)	0.50			1.00			10.00		
	Effluent (ug/L)	0.02	0.20	1.00	0.02	0.20	1.00	0.02	0.20	1.00
	Percent Removed	96.00	60.00	---	98.00	80.00	0.00	99.80	98.00	90.00
25-100	Total Capital Cost (K$)	125	125	---	125	125	---	125	125	125
0.024	O&M Cost (K$/year)	4	4	---	4	4	---	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	910	910	---	910	910	---	910	910	910
101-500	Total Capital Cost (K$)	190	190	---	190	190	---	190	190	190
0.087	O&M Cost (K$/year)	5	5	---	5	5	---	5	5	5
0.024	Total Production Cost (cents/1,000 gal)	310	310	---	310	310	---	310	310	310
501-1,000	Total Capital Cost (K$)	300	300	---	300	300	---	300	300	300
0.27	O&M Cost (K$/year)	8	8	---	8	8	---	8	8	8
0.086	Total Production Cost (cents/1,000 gal)	140	140	---	140	140	---	140	140	140
1,001-3,300	Total Capital Cost (K$)	480	480	---	480	480	---	480	480	480
0.65	O&M Cost (K$/year)	14	14	---	14	14	---	14	14	14
0.23	Total Production Cost (cents/1,000 gal)	80	80	---	80	80	---	80	80	80
3,301-10,000	Total Capital Cost (K$)	800	800	---	800	800	---	800	800	800
1.8	O&M Cost (K$/year)	30	30	---	30	30	---	30	30	30
0.7	Total Production Cost (cents/1,000 gal)	49	49	---	49	49	---	49	49	49
10,001-25,000	Total Capital Cost (K$)	1700	1700	---	1700	1700	---	1700	1700	1700
4.8	O&M Cost (K$/year)	70	70	---	70	70	---	70	70	70
2.1	Total Production Cost (cents/1,000 gal)	36	36	---	36	36	---	36	36	36
25,001-50,000	Total Capital Cost (K$)	3300	3300	---	3300	3300	---	3300	3300	3300
11.0	O&M Cost (K$/year)	130	130	---	130	130	---	130	130	130
5.0	Total Production Cost (cents/1,000 gal)	29	29	---	29	29	---	29	29	29
50,001-75,000	Total Capital Cost (K$)	5100	5100	---	5100	5100	---	5100	5100	5100
18.0	O&M Cost (K$/year)	200	200	---	200	200	---	200	200	200
8.8	Total Production Cost (cents/1,000 gal)	25	25	---	25	25	---	25	25	25
75,001-100,000	Total Capital Cost (K$)	6500	6500	---	6500	6500	---	6500	6500	6500
26.0	O&M Cost (K$/year)	300	300	---	300	300	---	300	300	300
13.0	Total Production Cost (cents/1,000 gal)	23	23	---	23	23	---	23	23	23
100,001-500,000	Total Capital Cost (K$)	13000	13000	---	13000	13000	---	13000	13000	13000
51.0	O&M Cost (K$/year)	400	400	---	400	400	---	400	400	400
27.0	Total Production Cost (cents/1,000 gal)	19	19	---	19	19	---	19	19	19
500,001-1,000,000	Total Capital Cost (K$)	36000	36000	---	36000	36000	---	36000	36000	36000
210.0	O&M Cost (K$/year)	1200	1200	---	1200	1200	---	1200	1200	1200
120.0	Total Production Cost (cents/1,000 gal)	12	12	---	12	12	---	12	12	12
>1,000,000	Total Capital Cost (K$)	63000	63000	---	63000	63000	---	63000	63000	63000
430.0	O&M Cost (K$/year)	2600	2600	---	2600	2600	---	2600	2600	2600
270.0	Total Production Cost (cents/1,000 gal)	10	10	---	10	10	---	10	10	10

GAC Adsorption -- Costs for Removing===> Methoxychlor

	Influent (ug/L)	260.00			400.00			1000.00		
Population Range	Effluent (ug/L)	100.00	400.00	500.00	100.00	400.00	500.00	100.00	400.00	500.00
Design Flow (MGD)										
Average Daily Flow (MGD)	Percent Removed	61.54	---	---	75.00	0.00	---	90.00	60.00	50.00
25-100	Total Capital Cost (K$)	125	---	---	125	---	---	125	125	125
0.024	O&M Cost (K$/year)	4	---	---	4	---	---	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	930	---	---	930	---	---	930	930	930
101-500	Total Capital Cost (K$)	190	---	---	190	---	---	190	190	190
0.087	O&M Cost (K$/year)	7	---	---	7	---	---	7	7	7
0.024	Total Production Cost (cents/1,000 gal)	330	---	---	330	---	---	330	330	330
501-1,000	Total Capital Cost (K$)	300	---	---	300	---	---	300	300	300
0.27	O&M Cost (K$/year)	13	---	---	13	---	---	13	13	13
0.086	Total Production Cost (cents/1,000 gal)	150	---	---	150	---	---	150	150	150
1,001-3,300	Total Capital Cost (K$)	480	---	---	480	---	---	480	480	480
0.65	O&M Cost (K$/year)	27	---	---	27	---	---	27	27	27
0.23	Total Production Cost (cents/1,000 gal)	100	---	---	100	---	---	100	100	100
3,301-10,000	Total Capital Cost (K$)	800	---	---	800	---	---	800	800	800
1.8	O&M Cost (K$/year)	70	---	---	70	---	---	70	70	70
0.7	Total Production Cost (cents/1,000 gal)	64	---	---	64	---	---	64	64	64
10,001-25,000	Total Capital Cost (K$)	1700	---	---	1700	---	---	1700	1700	1700
4.8	O&M Cost (K$/year)	190	---	---	190	---	---	190	190	190
2.1	Total Production Cost (cents/1,000 gal)	51	---	---	51	---	---	51	51	51
25,001-50,000	Total Capital Cost (K$)	3300	---	---	3300	---	---	3300	3300	3300
11.0	O&M Cost (K$/year)	400	---	---	400	---	---	400	400	400
5.0	Total Production Cost (cents/1,000 gal)	44	---	---	44	---	---	44	44	44
50,001-75,000	Total Capital Cost (K$)	7500	---	---	7500	---	---	7500	7500	7500
18.0	O&M Cost (K$/year)	300	---	---	300	---	---	300	300	300
8.8	Total Production Cost (cents/1,000 gal)	37	---	---	37	---	---	37	37	37
75,001-100,000	Total Capital Cost (K$)	9400	---	---	9400	---	---	9400	9400	9400
26.0	O&M Cost (K$/year)	400	---	---	400	---	---	400	400	400
13.0	Total Production Cost (cents/1,000 gal)	32	---	---	32	---	---	32	32	32
100,001-500,000	Total Capital Cost (K$)	14000	---	---	14000	---	---	14000	14000	14000
51.0	O&M Cost (K$/year)	700	---	---	700	---	---	700	700	700
27.0	Total Production Cost (cents/1,000 gal)	25	---	---	25	---	---	25	25	25
500,001-1,000,000	Total Capital Cost (K$)	39000	---	---	39000	---	---	39000	39000	39000
210.0	O&M Cost (K$/year)	2600	---	---	2600	---	---	2600	2600	2600
120.0	Total Production Cost (cents/1,000 gal)	16	---	---	16	---	---	16	16	16
>1,000,000	Total Capital Cost (K$)	67000	---	---	67000	---	---	67000	67000	67000
430.0	O&M Cost (K$/year)	5400	---	---	5400	---	---	5400	5400	5400
270.0	Total Production Cost (cents/1,000 gal)	14	---	---	14	---	---	14	14	14

GAC Adsorption -- Costs for Removing===> Monochlorobenzene

	Influent (ug/L)	100.00			600.00			1000.00		
Population Range Design Flow (MGD)	Effluent (ug/L)	60.00	100.00	400.00	60.00	100.00	400.00	60.00	100.00	400.00
Average Daily Flow (MGD)	Percent Removed	40.00	0.00	---	90.00	83.33	33.33	94.00	90.00	60.00
25-100	Total Capital Cost (K$)	125	---	---	125	125	125	125	125	125
0.024	O&M Cost (K$/year)	4	---	---	4	4	4	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	930	---	---	930	930	930	930	930	930
101-500	Total Capital Cost (K$)	190	---	---	190	190	190	190	190	190
0.087	O&M Cost (K$/year)	7	---	---	7	7	7	7	7	7
0.024	Total Production Cost (cents/1,000 gal)	330	---	---	330	330	330	330	330	330
501-1,000	Total Capital Cost (K$)	300	---	---	300	300	300	300	300	300
0.27	O&M Cost (K$/year)	13	---	---	13	13	13	13	13	13
0.086	Total Production Cost (cents/1,000 gal)	150	---	---	150	150	150	150	150	150
1,001-3,300	Total Capital Cost (K$)	480	---	---	480	480	480	480	480	480
0.65	O&M Cost (K$/year)	27	---	---	27	27	27	27	27	27
0.23	Total Production Cost (cents/1,000 gal)	100	---	---	100	100	100	100	100	100
3,301-10,000	Total Capital Cost (K$)	800	---	---	800	800	800	800	800	800
1.8	O&M Cost (K$/year)	70	---	---	70	70	70	70	70	70
0.7	Total Production Cost (cents/1,000 gal)	64	---	---	64	64	64	64	64	64
10,001-25,000	Total Capital Cost (K$)	1700	---	---	1700	1700	1700	1700	1700	1700
4.8	O&M Cost (K$/year)	190	---	---	190	190	190	190	190	190
2.1	Total Production Cost (cents/1,000 gal)	51	---	---	51	51	51	51	51	51
25,001-50,000	Total Capital Cost (K$)	3300	---	---	3300	3300	3300	3300	3300	3300
11.0	O&M Cost (K$/year)	400	---	---	400	400	400	400	400	400
5.0	Total Production Cost (cents/1,000 gal)	44	---	---	44	44	44	44	44	44
50,001-75,000	Total Capital Cost (K$)	7500	---	---	7500	7500	7500	7500	7500	7500
18.0	O&M Cost (K$/year)	300	---	---	300	300	300	300	300	300
8.8	Total Production Cost (cents/1,000 gal)	37	---	---	37	37	37	37	37	37
75,001-100,000	Total Capital Cost (K$)	9400	---	---	9400	9400	9400	9400	9400	9400
26.0	O&M Cost (K$/year)	400	---	---	400	400	400	400	400	400
13.0	Total Production Cost (cents/1,000 gal)	32	---	---	32	32	32	32	32	32
100,001-500,000	Total Capital Cost (K$)	14000	---	---	14000	14000	14000	14000	14000	14000
51.0	O&M Cost (K$/year)	700	---	---	700	700	700	700	700	700
27.0	Total Production Cost (cents/1,000 gal)	25	---	---	25	25	25	25	25	25
500,001-1,000,000	Total Capital Cost (K$)	39000	---	---	39000	39000	39000	39000	39000	39000
210.0	O&M Cost (K$/year)	2600	---	---	2600	2600	2600	2600	2600	2600
120.0	Total Production Cost (cents/1,000 gal)	16	---	---	16	16	16	16	16	16
>1,000,000	Total Capital Cost (K$)	67000	---	---	67000	67000	67000	67000	67000	67000
430.0	O&M Cost (K$/year)	5400	---	---	5400	5400	5400	5400	5400	5400
270.0	Total Production Cost (cents/1,000 gal)	14	---	---	14	14	14	14	14	14

GAC Adsorption -- Costs for Removing===> PCB (Aroclor 1254)

	Influent (ug/L)	5.00			10.00			50.00		
Population Range	Effluent (ug/L)	0.05	0.50	5.00	0.05	0.50	5.00	0.05	0.50	5.00
Design Flow (MGD)										
Average Daily Flow (MGD)	Percent Removed	99.00	90.00	0.00	99.50	95.00	50.00	99.90	99.00	90.00
25-100	Total Capital Cost (K$)	125	125	---	125	125	125	125	125	125
0.024	O&M Cost (K$/year)	4	4	---	4	4	4	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	910	910	---	910	910	910	910	910	910
101-500	Total Capital Cost (K$)	190	190	---	190	190	190	190	190	190
0.087	O&M Cost (K$/year)	5	5	---	5	5	5	5	5	5
0.024	Total Production Cost (cents/1,000 gal)	310	310	---	310	310	310	310	310	310
501-1,000	Total Capital Cost (K$)	300	300	---	300	300	300	300	300	300
0.27	O&M Cost (K$/year)	8	8	---	8	8	8	8	8	8
0.086	Total Production Cost (cents/1,000 gal)	140	140	---	140	140	140	140	140	140
1,001-3,300	Total Capital Cost (K$)	480	480	---	480	480	480	480	480	480
0.65	O&M Cost (K$/year)	14	14	---	14	14	14	14	14	14
0.23	Total Production Cost (cents/1,000 gal)	80	80	---	80	80	80	80	80	80
3,301-10,000	Total Capital Cost (K$)	800	800	---	800	800	800	800	800	800
1.8	O&M Cost (K$/year)	30	30	---	30	30	30	30	30	30
0.7	Total Production Cost (cents/1,000 gal)	49	49	---	49	49	49	49	49	49
10,001-25,000	Total Capital Cost (K$)	1700	1700	---	1700	1700	1700	1700	1700	1700
4.8	O&M Cost (K$/year)	70	70	---	70	70	70	70	70	70
2.1	Total Production Cost (cents/1,000 gal)	36	36	---	36	36	36	36	36	36
25,001-50,000	Total Capital Cost (K$)	3300	3300	---	3300	3300	3300	3300	3300	3300
11.0	O&M Cost (K$/year)	130	130	---	130	130	130	130	130	130
5.0	Total Production Cost (cents/1,000 gal)	29	29	---	29	29	29	29	29	29
50,001-75,000	Total Capital Cost (K$)	5100	5100	---	5100	5100	5100	5100	5100	5100
18.0	O&M Cost (K$/year)	200	200	---	200	200	200	200	200	200
8.8	Total Production Cost (cents/1,000 gal)	25	25	---	25	25	25	25	25	25
75,001-100,000	Total Capital Cost (K$)	6500	6500	---	6500	6500	6500	6500	6500	6500
26.0	O&M Cost (K$/year)	300	300	---	300	300	300	300	300	300
13.0	Total Production Cost (cents/1,000 gal)	23	23	---	23	23	23	23	23	23
100,001-500,000	Total Capital Cost (K$)	13000	13000	---	13000	13000	13000	13000	13000	13000
51.0	O&M Cost (K$/year)	400	400	---	400	400	400	400	400	400
27.0	Total Production Cost (cents/1,000 gal)	19	19	---	19	19	19	19	19	19
500,001-1,000,000	Total Capital Cost (K$)	36000	36000	---	36000	36000	36000	36000	36000	36000
210.0	O&M Cost (K$/year)	1200	1200	---	1200	1200	1200	1200	1200	1200
120.0	Total Production Cost (cents/1,000 gal)	12	12	---	12	12	12	12	12	12
>1,000,000	Total Capital Cost (K$)	63000	63000	---	63000	63000	63000	63000	63000	63000
430.0	O&M Cost (K$/year)	2600	2600	---	2600	2600	2600	2600	2600	2600
270.0	Total Production Cost (cents/1,000 gal)	10	10	---	10	10	10	10	10	10

GAC Adsorption -- Costs for Removing===> Pentachlorophenol

Population Range Design Flow (MGD) Average Daily Flow (MGD)	Influent (ug/L)	50.00			500.00			1000.00		
	Effluent (ug/L)	20.00	200.00	400.00	20.00	200.00	400.00	20.00	200.00	400.00
	Percent Removed	60.00	---	---	96.00	60.00	20.00	98.00	80.00	60.00
25-100	Total Capital Cost (K$)	125	---	---	125	125	125	125	125	125
0.024	O&M Cost (K$/year)	4	---	---	4	4	4	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	910	---	---	910	910	910	930	930	930
101-500	Total Capital Cost (K$)	190	---	---	190	190	190	190	190	190
0.087	O&M Cost (K$/year)	5	---	---	5	5	5	7	7	7
0.024	Total Production Cost (cents/1,000 gal)	310	---	---	310	310	310	330	330	330
501-1,000	Total Capital Cost (K$)	300	---	---	300	300	300	300	300	300
0.27	O&M Cost (K$/year)	8	---	---	8	8	8	13	13	13
0.086	Total Production Cost (cents/1,000 gal)	140	---	---	140	140	140	150	150	150
1,001-3,300	Total Capital Cost (K$)	480	---	---	480	480	480	480	480	480
0.65	O&M Cost (K$/year)	14	---	---	14	14	14	27	27	27
0.23	Total Production Cost (cents/1,000 gal)	80	---	---	80	80	80	100	100	100
3,301-10,000	Total Capital Cost (K$)	800	---	---	800	800	800	800	800	800
1.8	O&M Cost (K$/year)	30	---	---	30	30	30	70	70	70
0.7	Total Production Cost (cents/1,000 gal)	49	---	---	49	49	49	64	64	64
10,001-25,000	Total Capital Cost (K$)	1700	---	---	1700	1700	1700	1700	1700	1700
4.8	O&M Cost (K$/year)	70	---	---	70	70	70	190	190	190
2.1	Total Production Cost (cents/1,000 gal)	36	---	---	36	36	36	51	51	51
25,001-50,000	Total Capital Cost (K$)	3300	---	---	3300	3300	3300	3300	3300	3300
11.0	O&M Cost (K$/year)	130	---	---	130	130	130	400	400	400
5.0	Total Production Cost (cents/1,000 gal)	29	---	---	29	29	29	44	44	44
50,001-75,000	Total Capital Cost (K$)	5100	---	---	5100	5100	5100	7500	7500	7500
18.0	O&M Cost (K$/year)	200	---	---	200	200	200	300	300	300
8.8	Total Production Cost (cents/1,000 gal)	25	---	---	25	25	25	37	37	37
75,001-100,000	Total Capital Cost (K$)	6500	---	---	6500	6500	6500	9400	9400	9400
26.0	O&M Cost (K$/year)	300	---	---	300	300	300	400	400	400
13.0	Total Production Cost (cents/1,000 gal)	23	---	---	23	23	23	32	32	32
100,001-500,000	Total Capital Cost (K$)	13000	---	---	13000	13000	13000	14000	14000	14000
51.0	O&M Cost (K$/year)	400	---	---	400	400	400	700	700	700
27.0	Total Production Cost (cents/1,000 gal)	19	---	---	19	19	19	25	25	25
500,001-1,000,000	Total Capital Cost (K$)	36000	---	---	36000	36000	36000	39000	39000	39000
210.0	O&M Cost (K$/year)	1200	---	---	1200	1200	1200	2600	2600	2600
120.0	Total Production Cost (cents/1,000 gal)	12	---	---	12	12	12	16	16	16
>1,000,000	Total Capital Cost (K$)	63000	---	---	63000	63000	63000	67000	67000	67000
430.0	O&M Cost (K$/year)	2600	---	---	2600	2600	2600	5400	5400	5400
270.0	Total Production Cost (cents/1,000 gal)	10	---	---	10	10	10	14	14	14

GAC Adsorption -- Costs for Removing===> 2,4,5-TP (Silvex)

Population Range Design Flow (MGD) Average Daily Flow (MGD)	Influent (ug/L)	50.00			100.00			500.00		
	Effluent (ug/L)	5.00	50.00	100.00	5.00	50.00	100.00	5.00	50.00	100.00
	Percent Removed	90.00	0.00	---	95.00	50.00	0.00	99.00	90.00	80.00
25-100	Total Capital Cost (K$)	125	---	---	125	125	125	125	125	125
0.024	O&M Cost (K$/year)	4	---	---	4	4	4	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	910	---	---	910	910	910	930	930	930
101-500	Total Capital Cost (K$)	190	---	---	190	190	190	190	190	190
0.087	O&M Cost (K$/year)	5	---	---	5	5	5	7	7	7
0.024	Total Production Cost (cents/1,000 gal)	310	---	---	310	310	310	330	330	330
501-1,000	Total Capital Cost (K$)	300	---	---	300	300	300	300	300	300
0.27	O&M Cost (K$/year)	8	---	---	8	8	8	13	13	13
0.086	Total Production Cost (cents/1,000 gal)	140	---	---	140	140	140	150	150	150
1,001-3,300	Total Capital Cost (K$)	480	---	---	480	480	480	480	480	480
0.65	O&M Cost (K$/year)	14	---	---	14	14	14	27	27	27
0.23	Total Production Cost (cents/1,000 gal)	80	---	---	80	80	80	100	100	100
3,301-10,000	Total Capital Cost (K$)	800	---	---	800	800	800	800	800	800
1.8	O&M Cost (K$/year)	30	---	---	30	30	30	70	70	70
0.7	Total Production Cost (cents/1,000 gal)	49	---	---	49	49	49	64	64	64
10,001-25,000	Total Capital Cost (K$)	1700	---	---	1700	1700	1700	1700	1700	1700
4.8	O&M Cost (K$/year)	70	---	---	70	70	70	190	190	190
2.1	Total Production Cost (cents/1,000 gal)	36	---	---	36	36	36	51	51	51
25,001-50,000	Total Capital Cost (K$)	3300	---	---	3300	3300	3300	3300	3300	3300
11.0	O&M Cost (K$/year)	130	---	---	130	130	130	400	400	400
5.0	Total Production Cost (cents/1,000 gal)	29	---	---	29	29	29	44	44	44
50,001-75,000	Total Capital Cost (K$)	5100	---	---	5100	5100	5100	7500	7500	7500
18.0	O&M Cost (K$/year)	200	---	---	200	200	200	300	300	300
8.8	Total Production Cost (cents/1,000 gal)	25	---	---	25	25	25	37	37	37
75,001-100,000	Total Capital Cost (K$)	6500	---	---	6500	6500	6500	9400	9400	9400
26.0	O&M Cost (K$/year)	300	---	---	300	300	300	400	400	400
13.0	Total Production Cost (cents/1,000 gal)	23	---	---	23	23	23	32	32	32
100,001-500,000	Total Capital Cost (K$)	13000	---	---	13000	13000	13000	14000	14000	14000
51.0	O&M Cost (K$/year)	400	---	---	400	400	400	700	700	700
27.0	Total Production Cost (cents/1,000 gal)	19	---	---	19	19	19	25	25	25
500,001-1,000,000	Total Capital Cost (K$)	36000	---	---	36000	36000	36000	39000	39000	39000
210.0	O&M Cost (K$/year)	1200	---	---	1200	1200	1200	2600	2600	2600
120.0	Total Production Cost (cents/1,000 gal)	12	---	---	12	12	12	16	16	16
>1,000,000	Total Capital Cost (K$)	63000	---	---	63000	63000	63000	67000	67000	67000
430.0	O&M Cost (K$/year)	2600	---	---	2600	2600	2600	5400	5400	5400
270.0	Total Production Cost (cents/1,000 gal)	10	---	---	10	10	10	14	14	14

GAC Adsorption -- Costs for Removing===> Styrene

	Influent (ug/L)	10.00			50.00			200.00		
Population Range Design Flow (MGD) Average Daily Flow (MGD)	Effluent (ug/L)	2.00	5.00	20.00	2.00	5.00	20.00	2.00	5.00	20.00
	Percent Removed	80.00	50.00	---	96.00	90.00	60.00	99.00	97.50	90.00
25-100	Total Capital Cost (K$)	125	125	---	125	125	125	125	125	125
0.024	O&M Cost (K$/year)	4	4	---	4	4	4	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	910	910	---	910	910	910	910	910	910
101-500	Total Capital Cost (K$)	190	190	---	190	190	190	190	190	190
0.087	O&M Cost (K$/year)	5	5	---	5	5	5	5	5	5
0.024	Total Production Cost (cents/1,000 gal)	310	310	---	310	310	310	310	310	310
501-1,000	Total Capital Cost (K$)	300	300	---	300	300	300	300	300	300
0.27	O&M Cost (K$/year)	8	8	---	8	8	8	8	8	8
0.086	Total Production Cost (cents/1,000 gal)	140	140	---	140	140	140	140	140	140
1,001-3,300	Total Capital Cost (K$)	480	480	---	480	480	480	480	480	480
0.65	O&M Cost (K$/year)	14	14	---	14	14	14	14	14	14
0.23	Total Production Cost (cents/1,000 gal)	80	80	---	80	80	80	80	80	80
3,301-10,000	Total Capital Cost (K$)	800	800	---	800	800	800	800	800	800
1.8	O&M Cost (K$/year)	30	30	---	30	30	30	30	30	30
0.7	Total Production Cost (cents/1,000 gal)	49	49	---	49	49	49	49	49	49
10,001-25,000	Total Capital Cost (K$)	1700	1700	---	1700	1700	1700	1700	1700	1700
4.8	O&M Cost (K$/year)	70	70	---	70	70	70	70	70	70
2.1	Total Production Cost (cents/1,000 gal)	36	36	---	36	36	36	36	36	36
25,001-50,000	Total Capital Cost (K$)	3300	3300	---	3300	3300	3300	3300	3300	3300
11.0	O&M Cost (K$/year)	130	130	---	130	130	130	130	130	130
5.0	Total Production Cost (cents/1,000 gal)	29	29	---	29	29	29	29	29	29
50,001-75,000	Total Capital Cost (K$)	5100	5100	---	5100	5100	5100	5100	5100	5100
18.0	O&M Cost (K$/year)	200	200	---	200	200	200	200	200	200
8.8	Total Production Cost (cents/1,000 gal)	25	25	---	25	25	25	25	25	25
75,001-100,000	Total Capital Cost (K$)	6500	6500	---	6500	6500	6500	6500	6500	6500
26.0	O&M Cost (K$/year)	300	300	---	300	300	300	300	300	300
13.0	Total Production Cost (cents/1,000 gal)	23	23	---	23	23	23	23	23	23
100,001-500,000	Total Capital Cost (K$)	13000	13000	---	13000	13000	13000	13000	13000	13000
51.0	O&M Cost (K$/year)	400	400	---	400	400	400	400	400	400
27.0	Total Production Cost (cents/1,000 gal)	19	19	---	19	19	19	19	19	19
500,001-1,000,000	Total Capital Cost (K$)	36000	36000	---	36000	36000	36000	36000	36000	36000
210.0	O&M Cost (K$/year)	1200	1200	---	1200	1200	1200	1200	1200	1200
120.0	Total Production Cost (cents/1,000 gal)	12	12	---	12	12	12	12	12	12
>1,000,000	Total Capital Cost (K$)	63000	63000	---	63000	63000	63000	63000	63000	63000
430.0	O&M Cost (K$/year)	2600	2600	---	2600	2600	2600	2600	2600	2600
270.0	Total Production Cost (cents/1,000 gal)	10	10	---	10	10	10	10	10	10

GAC Adsorption -- Costs for Removing===> Tetrachloroethylene

	Influent (ug/L)	50.00			100.00			500.00		
Population Range Design Flow (MGD)	Effluent (ug/L)	1.00	5.00	50.00	1.00	5.00	50.00	1.00	5.00	50.00
Average Daily Flow (MGD)	Percent Removed	98.00	90.00	0.00	99.00	95.00	50.00	99.80	99.00	90.00
25-100	Total Capital Cost (K$)	125	125	---	125	125	125	125	125	125
0.024	O&M Cost (K$/year)	4	4	---	4	4	4	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	910	910	---	930	930	930	930	930	930
101-500	Total Capital Cost (K$)	190	190	---	190	190	190	190	190	190
0.087	O&M Cost (K$/year)	5	5	---	7	7	7	7	7	7
0.024	Total Production Cost (cents/1,000 gal)	310	310	---	330	330	330	330	330	330
501-1,000	Total Capital Cost (K$)	300	300	---	300	300	300	300	300	300
0.27	O&M Cost (K$/year)	8	8	---	13	13	13	13	13	13
0.086	Total Production Cost (cents/1,000 gal)	140	140	---	150	150	150	150	150	150
1,001-3,300	Total Capital Cost (K$)	480	480	---	480	480	480	480	480	480
0.65	O&M Cost (K$/year)	14	14	---	27	27	27	27	27	27
0.23	Total Production Cost (cents/1,000 gal)	80	80	---	100	100	100	100	100	100
3,301-10,000	Total Capital Cost (K$)	800	800	---	800	800	800	800	800	800
1.8	O&M Cost (K$/year)	30	30	---	70	70	70	70	70	70
0.7	Total Production Cost (cents/1,000 gal)	49	49	---	64	64	64	64	64	64
10,001-25,000	Total Capital Cost (K$)	1700	1700	---	1700	1700	1700	1700	1700	1700
4.8	O&M Cost (K$/year)	70	70	---	190	190	190	190	190	190
2.1	Total Production Cost (cents/1,000 gal)	36	36	---	51	51	51	51	51	51
25,001-50,000	Total Capital Cost (K$)	3300	3300	---	3300	3300	3300	3300	3300	3300
11.0	O&M Cost (K$/year)	130	130	---	400	400	400	400	400	400
5.0	Total Production Cost (cents/1,000 gal)	29	29	---	44	44	44	44	44	44
50,001-75,000	Total Capital Cost (K$)	5100	5100	---	7500	7500	7500	7500	7500	7500
18.0	O&M Cost (K$/year)	200	200	---	300	300	300	300	300	300
8.8	Total Production Cost (cents/1,000 gal)	25	25	---	37	37	37	37	37	37
75,001-100,000	Total Capital Cost (K$)	6500	6500	---	9400	9400	9400	9400	9400	9400
26.0	O&M Cost (K$/year)	300	300	---	400	400	400	400	400	400
13.0	Total Production Cost (cents/1,000 gal)	23	23	---	32	32	32	32	32	32
100,001-500,000	Total Capital Cost (K$)	13000	13000	---	14000	14000	14000	14000	14000	14000
51.0	O&M Cost (K$/year)	400	400	---	700	700	700	700	700	700
27.0	Total Production Cost (cents/1,000 gal)	19	19	---	25	25	25	25	25	25
500,001-1,000,000	Total Capital Cost (K$)	36000	36000	---	39000	39000	39000	39000	39000	39000
210.0	O&M Cost (K$/year)	1200	1200	---	2600	2600	2600	2600	2600	2600
120.0	Total Production Cost (cents/1,000 gal)	12	12	---	16	16	16	16	16	16
>1,000,000	Total Capital Cost (K$)	63000	63000	---	67000	67000	67000	67000	67000	67000
430.0	O&M Cost (K$/year)	2600	2600	---	5400	5400	5400	5400	5400	5400
270.0	Total Production Cost (cents/1,000 gal)	10	10	---	14	14	14	14	14	14

GAC Adsorption -- Costs for Removing===> Toluene

	Influent (ug/L)	500.00			3000.00			5000.00		
Population Range	Effluent (ug/L)	100.00	2000.00	3000.00	100.00	2000.00	3000.00	100.00	2000.00	3000.00
Design Flow (MGD)										
Average Daily Flow (MGD)	Percent Removed	80.00	---	---	96.67	33.33	0.00	98.00	60.00	40.00
25-100	Total Capital Cost (K$)	125	---	---	125	125	---	125	125	125
0.024	O&M Cost (K$/year)	4	---	---	5	5	---	5	5	5
0.0056	Total Production Cost (cents/1,000 gal)	930	---	---	950	950	---	950	950	950
101-500	Total Capital Cost (K$)	190	---	---	190	190	---	190	190	190
0.087	O&M Cost (K$/year)	7	---	---	9	9	---	9	9	9
0.024	Total Production Cost (cents/1,000 gal)	330	---	---	350	350	---	350	350	350
501-1,000	Total Capital Cost (K$)	300	---	---	300	300	---	300	300	300
0.27	O&M Cost (K$/year)	13	---	---	21	21	---	21	21	21
0.086	Total Production Cost (cents/1,000 gal)	150	---	---	180	180	---	180	180	180
1,001-3,300	Total Capital Cost (K$)	480	---	---	480	480	---	480	480	480
0.65	O&M Cost (K$/year)	27	---	---	48	48	---	48	48	48
0.23	Total Production Cost (cents/1,000 gal)	100	---	---	120	120	---	120	120	120
3,301-10,000	Total Capital Cost (K$)	800	---	---	800	800	---	800	800	800
1.8	O&M Cost (K$/year)	70	---	---	130	130	---	130	130	130
0.7	Total Production Cost (cents/1,000 gal)	64	---	---	89	89	---	89	89	89
10,001-25,000	Total Capital Cost (K$)	1700	---	---	1700	1700	---	1700	1700	1700
4.8	O&M Cost (K$/year)	190	---	---	380	380	---	380	380	380
2.1	Total Production Cost (cents/1,000 gal)	51	---	---	76	76	---	76	76	76
25,001-50,000	Total Capital Cost (K$)	3300	---	---	6000	6000	---	6000	6000	6000
11.0	O&M Cost (K$/year)	400	---	---	340	340	---	340	340	340
5.0	Total Production Cost (cents/1,000 gal)	44	---	---	58	58	---	58	58	58
50,001-75,000	Total Capital Cost (K$)	7500	---	---	8500	8500	---	8500	8500	8500
18.0	O&M Cost (K$/year)	300	---	---	500	500	---	500	500	500
8.8	Total Production Cost (cents/1,000 gal)	37	---	---	47	47	---	47	47	47
75,001-100,000	Total Capital Cost (K$)	9400	---	---	10000	10000	---	10000	10000	10000
26.0	O&M Cost (K$/year)	400	---	---	700	700	---	700	700	700
13.0	Total Production Cost (cents/1,000 gal)	32	---	---	41	41	---	41	41	41
100,001-500,000	Total Capital Cost (K$)	14000	---	---	16000	16000	---	16000	16000	16000
51.0	O&M Cost (K$/year)	700	---	---	1300	1300	---	1300	1300	1300
27.0	Total Production Cost (cents/1,000 gal)	25	---	---	32	32	---	32	32	32
500,001-1,000,000	Total Capital Cost (K$)	39000	---	---	42000	42000	---	42000	42000	42000
210.0	O&M Cost (K$/year)	2600	---	---	4700	4700	---	4700	4700	4700
120.0	Total Production Cost (cents/1,000 gal)	16	---	---	22	22	---	22	22	22
>1,000,000	Total Capital Cost (K$)	67000	---	---	71000	71000	---	71000	71000	71000
430.0	O&M Cost (K$/year)	5400	---	---	9900	9900	---	9900	9900	9900
270.0	Total Production Cost (cents/1,000 gal)	14	---	---	19	19	---	19	19	19

GAC Adsorption -- Costs for Removing===> Toxaphene

	Influent (ug/L)	5.00			10.00			50.00		
Population Range	Effluent (ug/L)	1.00	5.00	10.00	1.00	5.00	10.00	1.00	5.00	10.00
Design Flow (MGD)										
Average Daily Flow (MGD)	Percent Removed	80.00	0.00	---	90.00	50.00	0.00	98.00	90.00	80.00
25-100	Total Capital Cost (K$)	125	---	---	125	125	---	125	125	125
0.024	O&M Cost (K$/year)	4	---	---	4	4	---	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	910	---	---	910	910	---	910	910	910
101-500	Total Capital Cost (K$)	190	---	---	190	190	---	190	190	190
0.087	O&M Cost (K$/year)	5	---	---	5	5	---	5	5	5
0.024	Total Production Cost (cents/1,000 gal)	310	---	---	310	310	---	310	310	310
501-1,000	Total Capital Cost (K$)	300	---	---	300	300	---	300	300	300
0.27	O&M Cost (K$/year)	8	---	---	8	8	---	8	8	8
0.086	Total Production Cost (cents/1,000 gal)	140	---	---	140	140	---	140	140	140
1,001-3,300	Total Capital Cost (K$)	480	---	---	480	480	---	480	480	480
0.65	O&M Cost (K$/year)	14	---	---	14	14	---	14	14	14
0.23	Total Production Cost (cents/1,000 gal)	80	---	---	80	80	---	80	80	80
3,301-10,000	Total Capital Cost (K$)	800	---	---	800	800	---	800	800	800
1.8	O&M Cost (K$/year)	30	---	---	30	30	---	30	30	30
0.7	Total Production Cost (cents/1,000 gal)	49	---	---	49	49	---	49	49	49
10,001-25,000	Total Capital Cost (K$)	1700	---	---	1700	1700	---	1700	1700	1700
4.8	O&M Cost (K$/year)	70	---	---	70	70	---	70	70	70
2.1	Total Production Cost (cents/1,000 gal)	36	---	---	36	36	---	36	36	36
25,001-50,000	Total Capital Cost (K$)	3300	---	---	3300	3300	---	3300	3300	3300
11.0	O&M Cost (K$/year)	130	---	---	130	130	---	130	130	130
5.0	Total Production Cost (cents/1,000 gal)	29	---	---	29	29	---	29	29	29
50,001-75,000	Total Capital Cost (K$)	5100	---	---	5100	5100	---	5100	5100	5100
18.0	O&M Cost (K$/year)	200	---	---	200	200	---	200	200	200
8.8	Total Production Cost (cents/1,000 gal)	25	---	---	25	25	---	25	25	25
75,001-100,000	Total Capital Cost (K$)	6500	---	---	6500	6500	---	6500	6500	6500
26.0	O&M Cost (K$/year)	300	---	---	300	300	---	300	300	300
13.0	Total Production Cost (cents/1,000 gal)	23	---	---	23	23	---	23	23	23
100,001-500,000	Total Capital Cost (K$)	13000	---	---	13000	13000	---	13000	13000	13000
51.0	O&M Cost (K$/year)	400	---	---	400	400	---	400	400	400
27.0	Total Production Cost (cents/1,000 gal)	19	---	---	19	19	---	19	19	19
500,001-1,000,000	Total Capital Cost (K$)	36000	---	---	36000	36000	---	36000	36000	36000
210.0	O&M Cost (K$/year)	1200	---	---	1200	1200	---	1200	1200	1200
120.0	Total Production Cost (cents/1,000 gal)	12	---	---	12	12	---	12	12	12
>1,000,000	Total Capital Cost (K$)	63000	---	---	63000	63000	---	63000	63000	63000
430.0	O&M Cost (K$/year)	2600	---	---	2600	2600	---	2600	2600	2600
270.0	Total Production Cost (cents/1,000 gal)	10	---	---	10	10	---	10	10	10

GAC Adsorption -- Costs for Removing===> trans-1,2-Dichloroethylene

	Influent (ug/L)	50.00			200.00			500.00		
Population Range	Effluent (ug/L)	5.00	100.00	200.00	5.00	100.00	200.00	5.00	100.00	200.00
Design Flow (MGD)										
Average Daily Flow (MGD)	Percent Removed	90.00	---	---	97.50	50.00	0.00	99.00	80.00	60.00
25-100	Total Capital Cost (K$)	125	---	---	125	125	---	125	125	125
0.024	O&M Cost (K$/year)	4	---	---	5	5	---	5	5	5
0.0056	Total Production Cost (cents/1,000 gal)	930	---	---	950	950	---	950	950	950
101-500	Total Capital Cost (K$)	190	---	---	190	190	---	190	190	190
0.087	O&M Cost (K$/year)	7	---	---	9	9	---	9	9	9
0.024	Total Production Cost (cents/1,000 gal)	330	---	---	350	350	---	350	350	350
501-1,000	Total Capital Cost (K$)	300	---	---	300	300	---	300	300	300
0.27	O&M Cost (K$/year)	13	---	---	21	21	---	21	21	21
0.086	Total Production Cost (cents/1,000 gal)	150	---	---	180	180	---	180	180	180
1,001-3,300	Total Capital Cost (K$)	480	---	---	480	480	---	480	480	480
0.65	O&M Cost (K$/year)	27	---	---	48	48	---	48	48	48
0.23	Total Production Cost (cents/1,000 gal)	100	---	---	120	120	---	120	120	120
3,301-10,000	Total Capital Cost (K$)	800	---	---	800	800	---	800	800	800
1.8	O&M Cost (K$/year)	70	---	---	130	130	---	130	130	130
0.7	Total Production Cost (cents/1,000 gal)	64	---	---	89	89	---	89	89	89
10,001-25,000	Total Capital Cost (K$)	1700	---	---	1700	1700	---	1700	1700	1700
4.8	O&M Cost (K$/year)	190	---	---	380	380	---	380	380	380
2.1	Total Production Cost (cents/1,000 gal)	51	---	---	76	76	---	76	76	76
25,001-50,000	Total Capital Cost (K$)	3300	---	---	6000	6000	---	6000	6000	6000
11.0	O&M Cost (K$/year)	400	---	---	340	340	---	340	340	340
5.0	Total Production Cost (cents/1,000 gal)	44	---	---	58	58	---	58	58	58
50,001-75,000	Total Capital Cost (K$)	7500	---	---	8500	8500	---	8500	8500	8500
18.0	O&M Cost (K$/year)	300	---	---	500	500	---	500	500	500
8.8	Total Production Cost (cents/1,000 gal)	37	---	---	47	47	---	47	47	47
75,001-100,000	Total Capital Cost (K$)	9400	---	---	10000	10000	---	10000	10000	10000
26.0	O&M Cost (K$/year)	400	---	---	700	700	---	700	700	700
13.0	Total Production Cost (cents/1,000 gal)	32	---	---	41	41	---	41	41	41
100,001-500,000	Total Capital Cost (K$)	14000	---	---	16000	16000	---	16000	16000	16000
51.0	O&M Cost (K$/year)	700	---	---	1300	1300	---	1300	1300	1300
27.0	Total Production Cost (cents/1,000 gal)	25	---	---	32	32	---	32	32	32
500,001-1,000,000	Total Capital Cost (K$)	39000	---	---	42000	42000	---	42000	42000	42000
210.0	O&M Cost (K$/year)	2600	---	---	4700	4700	---	4700	4700	4700
120.0	Total Production Cost (cents/1,000 gal)	16	---	---	22	22	---	22	22	22
>1,000,000	Total Capital Cost (K$)	67000	---	---	71000	71000	---	71000	71000	71000
430.0	O&M Cost (K$/year)	5400	---	---	9900	9900	---	9900	9900	9900
270.0	Total Production Cost (cents/1,000 gal)	14	---	---	19	19	---	19	19	19

GAC Adsorption -- Costs for Removing===> m-Xylene

	Influent (ug/L)	10000.00			20000.00			50000.00		
Population Range	Effluent (ug/L)	1000.00	10000.00	15000.00	1000.00	10000.00	15000.00	1000.00	10000.00	15000.00
Design Flow (MGD)										
Average Daily Flow (MGD)	Percent Removed	90.00	0.00	---	95.00	50.00	25.00	98.00	80.00	70.00
25-100	Total Capital Cost (K$)	125	---	---	125	125	125	125	125	125
0.024	O&M Cost (K$/year)	4	---	---	4	4	4	4	4	4
0.0056	Total Production Cost (cents/1,000 gal)	930	---	---	930	930	930	930	930	930
101-500	Total Capital Cost (K$)	190	---	---	190	190	190	190	190	190
0.087	O&M Cost (K$/year)	7	---	---	7	7	7	7	7	7
0.024	Total Production Cost (cents/1,000 gal)	330	---	---	330	330	330	330	330	330
501-1,000	Total Capital Cost (K$)	300	---	---	300	300	300	300	300	300
0.27	O&M Cost (K$/year)	13	---	---	13	13	13	13	13	13
0.086	Total Production Cost (cents/1,000 gal)	150	---	---	150	150	150	150	150	150
1,001-3,300	Total Capital Cost (K$)	480	---	---	480	480	480	480	480	480
0.65	O&M Cost (K$/year)	27	---	---	27	27	27	27	27	27
0.23	Total Production Cost (cents/1,000 gal)	100	---	---	100	100	100	100	100	100
3,301-10,000	Total Capital Cost (K$)	800	---	---	800	800	800	800	800	800
1.8	O&M Cost (K$/year)	70	---	---	70	70	70	70	70	70
0.7	Total Production Cost (cents/1,000 gal)	64	---	---	64	64	64	64	64	64
10,001-25,000	Total Capital Cost (K$)	1700	---	---	1700	1700	1700	1700	1700	1700
4.8	O&M Cost (K$/year)	190	---	---	190	190	190	190	190	190
2.1	Total Production Cost (cents/1,000 gal)	51	---	---	51	51	51	51	51	51
25,001-50,000	Total Capital Cost (K$)	3300	---	---	3300	3300	3300	3300	3300	3300
11.0	O&M Cost (K$/year)	400	---	---	400	400	400	400	400	400
5.0	Total Production Cost (cents/1,000 gal)	44	---	---	44	44	44	44	44	44
50,001-75,000	Total Capital Cost (K$)	7500	---	---	7500	7500	7500	7500	7500	7500
18.0	O&M Cost (K$/year)	300	---	---	300	300	300	300	300	300
8.8	Total Production Cost (cents/1,000 gal)	37	---	---	37	37	37	37	37	37
75,001-100,000	Total Capital Cost (K$)	9400	---	---	9400	9400	9400	9400	9400	9400
26.0	O&M Cost (K$/year)	400	---	---	400	400	400	400	400	400
13.0	Total Production Cost (cents/1,000 gal)	32	---	---	32	32	32	32	32	32
100,001-500,000	Total Capital Cost (K$)	14000	---	---	14000	14000	14000	14000	14000	14000
51.0	O&M Cost (K$/year)	700	---	---	700	700	700	700	700	700
27.0	Total Production Cost (cents/1,000 gal)	25	---	---	25	25	25	25	25	25
500,001-1,000,000	Total Capital Cost (K$)	39000	---	---	39000	39000	39000	39000	39000	39000
210.0	O&M Cost (K$/year)	2600	---	---	2600	2600	2600	2600	2600	2600
120.0	Total Production Cost (cents/1,000 gal)	16	---	---	16	16	16	16	16	16
>1,000,000	Total Capital Cost (K$)	67000	---	---	67000	67000	67000	67000	67000	67000
430.0	O&M Cost (K$/year)	5400	---	---	5400	5400	5400	5400	5400	5400
270.0	Total Production Cost (cents/1,000 gal)	14	---	---	14	14	14	14	14	14

GAC Adsorption -- Costs for Removing===> o-Xylene

	Influent (ug/L)	10000.00			20000.00			50000.00		
Population Range Design Flow (MGD)	Effluent (ug/L)	1000.00	10000.00	15000.00	1000.00	10000.00	15000.00	1000.00	10000.00	15000.00
Average Daily Flow (MGD)	Percent Removed	90.00	0.00	---	95.00	50.00	25.00	98.00	80.00	70.00
25-100	Total Capital Cost (K$)	125	---	---	125	125	125	125	125	125
0.024	O&M Cost (K$/year)	5	---	---	5	5	5	5	5	5
0.0056	Total Production Cost (cents/1,000 gal)	950	---	---	950	950	950	950	950	950
101-500	Total Capital Cost (K$)	190	---	---	190	190	190	190	190	190
0.087	O&M Cost (K$/year)	9	---	---	9	9	9	9	9	9
0.024	Total Production Cost (cents/1,000 gal)	350	---	---	350	350	350	350	350	350
501-1,000	Total Capital Cost (K$)	300	---	---	300	300	300	300	300	300
0.27	O&M Cost (K$/year)	21	---	---	21	21	21	21	21	21
0.086	Total Production Cost (cents/1,000 gal)	180	---	---	180	180	180	180	180	180
1,001-3,300	Total Capital Cost (K$)	480	---	---	480	480	480	480	480	480
0.65	O&M Cost (K$/year)	48	---	---	48	48	48	48	48	48
0.23	Total Production Cost (cents/1,000 gal)	120	---	---	120	120	120	120	120	120
3,301-10,000	Total Capital Cost (K$)	800	---	---	800	800	800	800	800	800
1.8	O&M Cost (K$/year)	130	---	---	130	130	130	130	130	130
0.7	Total Production Cost (cents/1,000 gal)	89	---	---	89	89	89	89	89	89
10,001-25,000	Total Capital Cost (K$)	1700	---	---	1700	1700	1700	1700	1700	1700
4.8	O&M Cost (K$/year)	380	---	---	380	380	380	380	380	380
2.1	Total Production Cost (cents/1,000 gal)	76	---	---	76	76	76	76	76	76
25,001-50,000	Total Capital Cost (K$)	6000	---	---	6000	6000	6000	6000	6000	6000
11.0	O&M Cost (K$/year)	340	---	---	340	340	340	340	340	340
5.0	Total Production Cost (cents/1,000 gal)	58	---	---	58	58	58	58	58	58
50,001-75,000	Total Capital Cost (K$)	8500	---	---	8500	8500	8500	8500	8500	8500
18.0	O&M Cost (K$/year)	500	---	---	500	500	500	500	500	500
8.8	Total Production Cost (cents/1,000 gal)	47	---	---	47	47	47	47	47	47
75,001-100,000	Total Capital Cost (K$)	10000	---	---	10000	10000	10000	10000	10000	10000
26.0	O&M Cost (K$/year)	700	---	---	700	700	700	700	700	700
13.0	Total Production Cost (cents/1,000 gal)	41	---	---	41	41	41	41	41	41
100,001-500,000	Total Capital Cost (K$)	16000	---	---	16000	16000	16000	16000	16000	16000
51.0	O&M Cost (K$/year)	1300	---	---	1300	1300	1300	1300	1300	1300
27.0	Total Production Cost (cents/1,000 gal)	32	---	---	32	32	32	32	32	32
500,001-1,000,000	Total Capital Cost (K$)	42000	---	---	42000	42000	42000	42000	42000	42000
210.0	O&M Cost (K$/year)	4700	---	---	4700	4700	4700	4700	4700	4700
120.0	Total Production Cost (cents/1,000 gal)	22	---	---	22	22	22	22	22	22
>1,000,000	Total Capital Cost (K$)	71000	---	---	71000	71000	71000	71000	71000	71000
430.0	O&M Cost (K$/year)	9900	---	---	9900	9900	9900	9900	9900	9900
270.0	Total Production Cost (cents/1,000 gal)	19	---	---	19	19	19	19	19	19

GAC Adsorption -- Costs for Removing===> p-Xylene

	Influent (ug/L)	10000.00			20000.00			50000.00		
Population Range	Effluent (ug/L)	1000.00	10000.00	15000.00	1000.00	10000.00	15000.00	1000.00	10000.00	15000.00
Design Flow (MGD)										
Average Daily Flow (MGD)	Percent Removed	90.00	0.00	---	95.00	50.00	25.00	98.00	80.00	70.00
25-100	Total Capital Cost (K$)	125	---	---	125	125	125	125	125	125
0.024	O&M Cost (K$/year)	5	---	---	5	5	5	5	5	5
0.0056	Total Production Cost (cents/1,000 gal)	950	---	---	950	950	950	950	950	950
101-500	Total Capital Cost (K$)	190	---	---	190	190	190	190	190	190
0.087	O&M Cost (K$/year)	9	---	---	9	9	9	9	9	9
0.024	Total Production Cost (cents/1,000 gal)	350	---	---	350	350	350	350	350	350
501-1,000	Total Capital Cost (K$)	300	---	---	300	300	300	300	300	300
0.27	O&M Cost (K$/year)	21	---	---	21	21	21	21	21	21
0.086	Total Production Cost (cents/1,000 gal)	180	---	---	180	180	180	180	180	180
1,001-3,300	Total Capital Cost (K$)	480	---	---	480	480	480	480	480	480
0.65	O&M Cost (K$/year)	48	---	---	48	48	48	48	48	48
0.23	Total Production Cost (cents/1,000 gal)	120	---	---	120	120	120	120	120	120
3,301-10,000	Total Capital Cost (K$)	800	---	---	800	800	800	800	800	800
1.8	O&M Cost (K$/year)	130	---	---	130	130	130	130	130	130
0.7	Total Production Cost (cents/1,000 gal)	89	---	---	89	89	89	89	89	89
10,001-25,000	Total Capital Cost (K$)	1700	---	---	1700	1700	1700	1700	1700	1700
4.8	O&M Cost (K$/year)	380	---	---	380	380	380	380	380	380
2.1	Total Production Cost (cents/1,000 gal)	76	---	---	76	76	76	76	76	76
25,001-50,000	Total Capital Cost (K$)	6000	---	---	6000	6000	6000	6000	6000	6000
11.0	O&M Cost (K$/year)	340	---	---	340	340	340	340	340	340
5.0	Total Production Cost (cents/1,000 gal)	58	---	---	58	58	58	58	58	58
50,001-75,000	Total Capital Cost (K$)	8500	---	---	8500	8500	8500	8500	8500	8500
18.0	O&M Cost (K$/year)	500	---	---	500	500	500	500	500	500
8.8	Total Production Cost (cents/1,000 gal)	47	---	---	47	47	47	47	47	47
75,001-100,000	Total Capital Cost (K$)	10000	---	---	10000	10000	10000	10000	10000	10000
26.0	O&M Cost (K$/year)	700	---	---	700	700	700	700	700	700
13.0	Total Production Cost (cents/1,000 gal)	41	---	---	41	41	41	41	41	41
100,001-500,000	Total Capital Cost (K$)	16000	---	---	16000	16000	16000	16000	16000	16000
51.0	O&M Cost (K$/year)	1300	---	---	1300	1300	1300	1300	1300	1300
27.0	Total Production Cost (cents/1,000 gal)	32	---	---	32	32	32	32	32	32
500,001-1,000,000	Total Capital Cost (K$)	42000	---	---	42000	42000	42000	42000	42000	42000
210.0	O&M Cost (K$/year)	4700	---	---	4700	4700	4700	4700	4700	4700
120.0	Total Production Cost (cents/1,000 gal)	22	---	---	22	22	22	22	22	22
>1,000,000	Total Capital Cost (K$)	71000	---	---	71000	71000	71000	71000	71000	71000
430.0	O&M Cost (K$/year)	9900	---	---	9900	9900	9900	9900	9900	9900
270.0	Total Production Cost (cents/1,000 gal)	19	---	---	19	19	19	19	19	19

APPENDIX G

PACKED COLUMN FACILITY DESIGN BACKUP

Estimated Equipment Size and Cost for
Removal of Phase II SOCs from Drinking Water
Via
Packed Column Air Stripping

March 1989

Compound:

Monochlorobenzene

Henry's Coefficient = 0.06 at 12 Deg. C

U.S. Environmental Protection Agency
Office of Drinking Water
Technical Support Division
Cincinnati, Ohio 45268

Monochlorobenzene

Table 1
DESIGN CRITERIA - March 1989

Design Number	Plant Capacity (MGD)	Average Flow (MGD)	Removal Efficiency (%)	Cost Optimized Parameters	
				Stripping Fractor	Air Gradient (N m-2 m-1)
1	0.024	0.006	33.	1.0*	50.*
2	0.024	0.006	40.	1.0*	50.*
3	0.024	0.006	60.	1.4*	88.
4	0.024	0.006	83.	1.9*	160.
5	0.024	0.006	90.	2.2	170.
6	0.024	0.006	94.	2.4	160.
7	0.087	0.024	33.	1.0*	50.*
8	0.087	0.024	40.	1.0*	50.*
9	0.087	0.024	60.	1.1*	61.
10	0.087	0.024	83.	2.3	150.
11	0.087	0.024	90.	2.7	140.
12	0.087	0.024	94.	3.0	140.
13	0.270	0.086	33.	1.0*	50.*
14	0.270	0.086	40.	1.1*	57.
15	0.270	0.086	60.	1.5*	100.
16	0.270	0.086	83.	2.1	150.
17	0.270	0.086	90.	2.4	140.
18	0.270	0.086	94.	2.6	140.
19	0.650	0.230	33.	1.0*	50.*
20	0.650	0.230	40.	1.0*	50.*
21	0.650	0.230	60.	1.4*	91.
22	0.650	0.230	83.	1.9	140.
23	0.650	0.230	90.	2.2	130.
24	0.650	0.230	94.	2.4	130.
25	1.80	0.700	33.	1.0*	50.*
26	1.80	0.700	40.	1.0*	50.*
27	1.80	0.700	60.	1.3*	80.
28	1.80	0.700	83.	1.8	120.
29	1.80	0.700	90.	2.1	120.
30	1.80	0.700	94.	2.3	110.
31	4.80	2.10	33.	1.0*	50.*
32	4.80	2.10	40.	1.0*	50.*
33	4.80	2.10	60.	1.2*	71.
34	4.80	2.10	83.	1.7	100.
35	4.80	2.10	90.	2.0	99.
36	4.80	2.10	94.	2.2	97.

* Design parameter held to limiting value.

Monochlorobenzene

Table 2
SYSTEM SIZE - March 1989

Design Number	Loadings		Air: Water Ratio	Mass Trans. Coef. (sec-1)	Number of Columns	Column Diameter (ft)	Packing Height (ft)	Air Flow (SCFM)	Air Pressure (inch H2O)
	Liquid (GPM ft-2)	Air (SCFM ft-2)							
1	30.	73.	18.	0.013	1.0	0.8	2.8	41.	2.2
2	30.	73.	18.	0.013	1.0	0.8	3.8	41.	2.2
3	30.	100.	26.	0.014	1.0	0.8	6.7	58.	2.7
4	30.	140.	35.	0.014	1.0	0.8	13.	79.	4.6
5	28.	150.	40.	0.014	1.0	0.9	17.	88.	5.4
6	26.	150.	44.	0.013	1.0	0.9	20.	98.	5.8
7	30.	73.	18.	0.013	1.0	1.6	2.8	150.	2.2
8	30.	73.	18.	0.013	1.0	1.6	3.8	150.	2.2
9	30.	84.	21.	0.013	1.0	1.6	7.7	170.	2.6
10	26.	150.	43.	0.013	1.0	1.7	12.	350.	4.1
11	24.	150.	49.	0.012	1.0	1.8	15.	400.	4.6
12	22.	160.	54.	0.011	1.0	1.9	17.	440.	5.0
13	30.	73.	18.	0.013	1.0	2.8	2.8	460.	2.2
14	30.	80.	20.	0.013	1.0	2.8	3.6	500.	2.3
15	30.	110.	28.	0.014	1.0	2.8	6.5	710.	2.8
16	28.	150.	38.	0.014	1.0	2.9	13.	960.	4.4
17	26.	150.	44.	0.013	1.0	3.1	16.	1100.	4.8
18	24.	150.	48.	0.012	1.0	3.2	19.	1200.	5.2
19	30.	73.	18.	0.013	1.0	4.4	2.8	1100.	2.2
20	30.	73.	18.	0.013	1.0	4.4	3.8	1100.	2.2
21	30.	110.	26.	0.014	1.0	4.4	6.7	1600.	2.8
22	29.	140.	35.	0.014	1.0	4.5	13.	2100.	4.3
23	26.	140.	41.	0.013	1.0	4.7	16.	2500.	4.7
24	24.	140.	45.	0.012	1.0	4.9	19.	2700.	5.0
25	30.	73.	18.	0.013	1.0	7.3	2.8	3100.	2.2
26	30.	73.	18.	0.013	1.0	7.3	3.8	3100.	2.2
27	30.	98.	24.	0.014	1.0	7.3	7.0	4100.	2.7
28	29.	130.	33.	0.013	1.0	7.5	14.	5600.	4.0
29	26.	130.	38.	0.013	1.0	7.8	17.	6400.	4.4
30	24.	130.	42.	0.012	1.0	8.1	20.	7000.	4.7
31	30.	73.	18.	0.013	1.0	11.9	2.8	8200.	2.2
32	30.	73.	18.	0.013	1.0	11.9	3.8	8200.	2.2
33	30.	92.	23.	0.013	1.0	11.9	7.2	10000.	2.6
34	28.	120.	32.	0.013	1.0	12.3	14.	14000.	3.8
35	25.	120.	36.	0.012	1.0	13.0	17.	16000.	4.1
36	24.	130.	40.	0.012	1.0	13.4	21.	18000.	4.4

Monochlorobenzene

Table 3
ESTIMATED COST - March 1989

Design Number	Estimated Capital Costs				Operating Cost ($K Year-1)	Yearly Cost ($K Year-1)	Production Cost ($ Kgal-1)
	Process ($K)	Support ($K)	Indirect ($K)	Total ($K)			
1	2.2	6.8	5.9	15.	0.21	2.0	0.96
2	2.3	6.9	6.0	15.	0.22	2.0	0.98
3	2.9	7.2	6.6	17.	0.27	2.2	1.10
4	4.2	8.0	8.0	20.	0.37	2.7	1.34
5	5.0	8.4	8.8	22.	0.43	3.0	1.48
6	5.7	8.9	9.6	24.	0.49	3.3	1.63
7	5.1	11.	10.	27.	0.64	3.8	0.43
8	5.4	11.	11.	27.	0.66	3.9	0.44
9	6.8	12.	12.	31.	0.77	4.4	0.50
10	9.2	14.	15.	38.	1.1	5.5	0.62
11	11.	14.	16.	41.	1.2	6.0	0.69
12	12.	15.	18.	45.	1.3	6.6	0.75
13	8.1	17.	16.	41.	1.4	6.2	0.20
14	8.6	17.	17.	42.	1.4	6.4	0.20
15	11.	18.	19.	48.	1.7	7.3	0.23
16	15.	21.	24.	60.	2.3	9.4	0.30
17	18.	23.	27.	68.	2.6	11.	0.34
18	21.	25.	30.	76.	2.9	12.	0.37
19	13.	25.	24.	62.	2.9	10.	0.12
20	14.	25.	26.	65.	3.0	11.	0.13
21	17.	28.	29.	74.	3.5	12.	0.15
22	25.	33.	38.	96.	4.8	16.	0.19
23	30.	36.	44.	110.	5.5	18.	0.22
24	35.	40.	49.	120.	6.1	21.	0.25
25	24.	43.	44.	110.	7.5	21.	0.08
26	26.	45.	46.	120.	7.8	21.	0.08
27	33.	50.	54.	140.	9.2	25.	0.10
28	50.	61.	72.	180.	12.	34.	0.13
29	60.	68.	84.	210.	14.	39.	0.15
30	70.	75.	95.	240.	16.	44.	0.17
31	50.	84.	87.	220.	21.	47.	0.06
32	54.	86.	92.	230.	22.	49.	0.06
33	70.	98.	110.	280.	25.	58.	0.08
34	100.	120.	150.	380.	34.	78.	0.10
35	130.	140.	170.	440.	38.	90.	0.12
36	150.	150.	200.	500.	42.	100.	0.13

o-Dichlorobenzene

Table 2 (continued)
SYSTEM SIZE - March 1989

Design Number	Loadings Liquid (GPM ft-2)	Loadings Air (SCFM ft-2)	Air: Water Ratio	Mass Trans. Coef. (sec-1)	Number of Columns	Column Diameter (ft)	Packing Height (ft)	Air Flow (SCFM)	Air Pressure (inch H2O)
37	30.	140.	35.	0.012	1.3	16.0	1.0	36000.	2.2
38	30.	140.	35.	0.012	1.3	16.0	1.6	36000.	2.3
39	29.	140.	35.	0.012	1.3	16.0	4.1	36000.	2.7
40	29.	140.	35.	0.011	1.3	16.0	6.2	36000.	3.0
41	17.	150.	65.	0.0083	2.2	16.0	22.	66000.	4.8
42	17.	150.	68.	0.0080	2.3	16.0	24.	70000.	5.0
43	30.	140.	35.	0.012	2.1	16.0	1.0	59000.	2.2
44	29.	140.	35.	0.012	2.1	16.0	1.6	59000.	2.3
45	29.	140.	35.	0.011	2.2	16.0	4.1	59000.	2.7
46	28.	140.	35.	0.011	2.2	16.0	6.2	59000.	3.0
47	17.	150.	65.	0.0081	3.7	16.0	22.	110000.	4.6
48	16.	150.	68.	0.0079	3.8	16.0	24.	110000.	4.9
49	30.	140.	35.	0.012	3.0	16.0	1.0	86000.	2.2
50	29.	140.	35.	0.012	3.0	16.0	1.6	86000.	2.3
51	29.	140.	35.	0.011	3.1	16.0	4.1	86000.	2.7
52	28.	130.	35.	0.011	3.2	16.0	6.2	86000.	3.0
53	17.	150.	65.	0.0081	5.3	16.0	22.	160000.	4.6
54	16.	150.	68.	0.0079	5.6	16.0	24.	160000.	4.8
55	30.	140.	35.	0.012	6.0	16.0	1.0	170000.	2.2
56	29.	140.	35.	0.012	6.0	16.0	1.6	170000.	2.3
57	29.	140.	35.	0.011	6.2	16.0	4.1	170000.	2.7
58	28.	130.	35.	0.011	6.3	16.0	6.2	170000.	3.0
59	17.	140.	64.	0.0080	10.6	16.0	22.	310000.	4.4
60	16.	140.	68.	0.0077	11.1	16.0	24.	320000.	4.7
61	29.	140.	35.	0.012	24.7	16.0	1.0	690000.	2.2
62	29.	140.	35.	0.012	24.9	16.0	1.6	690000.	2.3
63	28.	130.	35.	0.011	25.6	16.0	4.1	690000.	2.7
64	28.	130.	36.	0.011	26.1	16.0	6.1	690000.	2.9
65	16.	140.	64.	0.0078	45.1	16.0	22.	1300000.	4.2
66	15.	140.	68.	0.0076	47.2	16.0	24.	1300000.	4.4
67	29.	140.	35.	0.012	50.8	16.0	1.0	1400000.	2.2
68	29.	140.	35.	0.012	51.2	16.0	1.5	1400000.	2.3
69	28.	130.	35.	0.011	52.9	16.0	4.1	1400000.	2.7
70	27.	130.	36.	0.011	54.0	16.0	6.1	1400000.	2.9
71	16.	130.	64.	0.0076	95.1	16.0	22.	2600000.	4.1
72	15.	140.	68.	0.0074	99.3	16.0	24.	2700000.	4.3

o-Dichlorobenzene

Table 1 (continued)
DESIGN CRITERIA - March 1989

Design Number	Plant Capacity (MGD)	Average Flow (MGD)	Removal Efficiency (%)	Cost Optimized Parameters Stripping Fractor	Cost Optimized Parameters Air Gradient (N m-2 m-1)
37	11.0	5.00	14.	1.0	150.
38	11.0	5.00	20.	1.0	150.
39	11.0	5.00	40.	1.0	140.
40	11.0	5.00	50.	1.0	140.
41	11.0	5.00	92.9	1.8	100.
42	11.0	5.00	95.	1.9	100.
43	18.0	8.80	14.	1.0	150.
44	18.0	8.80	20.	1.0	150.
45	18.0	8.80	40.	1.0	140.
46	18.0	8.80	50.	1.0	130.
47	18.0	8.80	92.9	1.8	96.
48	18.0	8.80	95.	1.9	96.
49	26.0	13.0	14.	1.0	150.
50	26.0	13.0	20.	1.0	150.
51	26.0	13.0	40.	1.0	140.
52	26.0	13.0	50.	1.0	130.
53	26.0	13.0	92.9	1.8	95.
54	26.0	13.0	95.	1.9	94.
55	51.0	27.0	14.	1.0	150.
56	51.0	27.0	20.	1.0	150.
57	51.0	27.0	40.	1.0	140.
58	51.0	27.0	50.	1.0	130.
59	51.0	27.0	92.9	1.8	90.
60	51.0	27.0	95.	1.9	89.
61	210.	120.	14.	1.0	150.
62	210.	120.	20.	1.0	140.
63	210.	120.	40.	1.0	130.
64	210.	120.	50.	1.0	130.
65	210.	120.	92.9	1.8	83.
66	210.	120.	95.	1.9	82.
67	430.	270.	14.	1.0	140.
68	430.	270.	20.	1.0	140.
69	430.	270.	40.	1.0	130.
70	430.	270.	50.	1.0	120.
71	430.	270.	92.9	1.8	77.
72	430.	270.	95.	1.9	76.

m-Xylene

Table 3 (continued)
ESTIMATED COST - March 1989

Design Number	Estimated Capital Costs				Operating Cost	Yearly Cost	Production Cost
	Process ($K)	Support ($K)	Indirect ($K)	Total ($K)	($K Year-1)	($K Year-1)	($ Kgal-1)
43	94.	150.	160.	410.	47.	95.	0.05
44	110.	160.	170.	440.	49.	100.	0.06
45	150.	190.	220.	570.	57.	120.	0.07
46	160.	200.	240.	610.	61.	130.	0.07
47	220.	250.	300.	770.	75.	170.	0.09
48	260.	280.	360.	900.	87.	190.	0.11
49	320.	320.	420.	1100.	100.	230.	0.12
50	150.	230.	250.	630.	81.	150.	0.05
51	170.	250.	270.	690.	85.	170.	0.05
52	240.	300.	350.	890.	99.	200.	0.06
53	260.	320.	380.	960.	100.	220.	0.07
54	350.	380.	480.	1200.	130.	270.	0.08
55	420.	440.	560.	1400.	150.	320.	0.10
56	520.	510.	670.	1700.	170.	370.	0.12
57	210.	320.	350.	880.	120.	220.	0.05
58	240.	340.	380.	960.	120.	240.	0.05
59	340.	420.	490.	1200.	150.	290.	0.06
60	370.	440.	530.	1300.	150.	310.	0.07
61	500.	540.	680.	1700.	190.	390.	0.08
62	600.	610.	800.	2000.	220.	450.	0.10
63	740.	710.	950.	2400.	260.	540.	0.11
64	410.	570.	640.	1600.	250.	430.	0.04
65	460.	610.	700.	1800.	260.	460.	0.05
66	650.	750.	920.	2300.	300.	570.	0.06
67	710.	800.	990.	2500.	320.	610.	0.06
68	960.	990.	1300.	3200.	390.	770.	0.08
69	1100.	1100.	1500.	3800.	450.	890.	0.09
70	1400.	1300.	1800.	4500.	520.	1100.	0.11
71	1600.	1800.	2200.	5700.	1200.	1800.	0.04
72	1800.	2000.	2500.	6300.	1200.	1900.	0.04
73	2500.	2500.	3300.	8400.	1400.	2400.	0.05
74	2800.	2700.	3600.	9100.	1500.	2500.	0.06
75	3700.	3500.	4700.	12000.	1800.	3200.	0.07
76	4500.	4100.	5600.	14000.	2000.	3700.	0.08
77	5500.	4900.	6800.	17000.	2400.	4400.	0.10
78	3300.	3400.	4300.	11000.	2700.	4000.	0.04
79	3600.	3700.	4800.	12000.	2800.	4200.	0.04
80	5100.	4800.	6500.	16000.	3200.	5100.	0.05
81	5600.	5200.	7100.	18000.	3400.	5500.	0.06
82	7500.	6700.	9300.	24000.	4100.	6800.	0.07
83	9000.	7900.	11000.	28000.	4600.	7900.	0.08
84	11000.	9600.	14000.	34000.	5300.	9300.	0.09

m-Xylene

Table 2 (continued)
SYSTEM SIZE - March 1989

Design Number	Loadings		Air: Water Ratio	Mass Trans. Coef. (sec-1)	Number of Columns	Column Diameter (ft)	Packing Height (ft)	Air Flow (SCFM)	Air Pressure (inch H2O)
	Liquid (GPM ft-2)	Air (SCFM ft-2)							
43	30.	73.	18.	0.014	1.3	16.0	1.7	19000.	2.1
44	30.	73.	18.	0.014	1.3	16.0	3.2	19000.	2.2
45	30.	73.	18.	0.014	1.3	16.0	8.7	19000.	2.5
46	30.	79.	20.	0.014	1.3	16.0	10.	20000.	2.7
47	30.	96.	24.	0.014	1.3	16.0	17.	24000.	3.6
48	30.	100.	26.	0.014	1.3	16.0	22.	26000.	4.4
49	30.	110.	27.	0.014	1.3	16.0	29.	28000.	5.4
50	30.	73.	18.	0.014	2.1	16.0	1.7	31000.	2.1
51	30.	73.	18.	0.014	2.1	16.0	3.2	31000.	2.2
52	30.	73.	18.	0.014	2.1	16.0	8.7	31000.	2.5
53	30.	79.	20.	0.014	2.1	16.0	10.	33000.	2.7
54	30.	95.	24.	0.014	2.1	16.0	17.	40000.	3.6
55	30.	100.	26.	0.014	2.1	16.0	22.	43000.	4.3
56	30.	110.	27.	0.014	2.1	16.0	29.	45000.	5.4
57	30.	73.	18.	0.014	3.0	16.0	1.7	44000.	2.1
58	30.	73.	18.	0.014	3.0	16.0	3.2	44000.	2.2
59	30.	73.	18.	0.014	3.0	16.0	8.7	44000.	2.5
60	30.	78.	19.	0.014	3.0	16.0	10.	47000.	2.7
61	30.	95.	24.	0.014	3.0	16.0	17.	57000.	3.6
62	30.	100.	25.	0.014	3.0	16.0	22.	61000.	4.3
63	30.	110.	27.	0.014	3.0	16.0	29.	65000.	5.4
64	30.	73.	18.	0.014	5.9	16.0	1.7	87000.	2.1
65	30.	73.	18.	0.014	5.9	16.0	3.2	87000.	2.2
66	30.	73.	18.	0.014	5.9	16.0	8.7	87000.	2.5
67	30.	77.	19.	0.014	5.9	16.0	10.	91000.	2.7
68	30.	94.	23.	0.014	5.9	16.0	17.	110000.	3.6
69	30.	100.	25.	0.014	5.9	16.0	22.	120000.	4.3
70	30.	110.	27.	0.014	5.9	16.0	29.	130000.	5.3
71	30.	73.	18.	0.014	24.2	16.0	1.7	360000.	2.1
72	30.	73.	18.	0.014	24.2	16.0	3.2	360000.	2.2
73	30.	73.	18.	0.014	24.2	16.0	8.7	360000.	2.5
74	30.	76.	19.	0.014	24.2	16.0	10.	370000.	2.7
75	30.	92.	23.	0.014	24.2	16.0	17.	450000.	3.5
76	30.	99.	25.	0.014	24.2	16.0	23.	480000.	4.2
77	30.	100.	26.	0.014	24.4	16.0	29.	510000.	5.2
78	30.	73.	18.	0.014	49.5	16.0	1.7	730000.	2.1
79	30.	73.	18.	0.014	49.5	16.0	3.2	730000.	2.2
80	30.	73.	18.	0.014	49.5	16.0	8.7	730000.	2.5
81	30.	75.	19.	0.014	49.5	16.0	11.	740000.	2.7
82	30.	91.	23.	0.014	49.5	16.0	17.	900000.	3.5
83	30.	98.	24.	0.014	49.5	16.0	23.	970000.	4.2
84	29.	100.	26.	0.014	51.6	16.0	29.	1100000.	4.9

m-Xylene

Table 1 (continued)
DESIGN CRITERIA - March 1989

Design Number	Plant Capacity (MGD)	Average Flow (MGD)	Removal Efficiency (%)	Cost Optimized Parameters	
				Stripping Fractor	Air Gradient (N m-2 m-1)
43	11.0	5.00	25.	1.8*	50.*
44	11.0	5.00	40.	1.8*	50.*
45	11.0	5.00	70.	1.8*	50.*
46	11.0	5.00	76.	2.0*	56.
47	11.0	5.00	90.	2.4*	77.
48	11.0	5.00	95.	2.6*	88.
49	11.0	5.00	98.	2.7*	97.
50	18.0	8.80	25.	1.8*	50.*
51	18.0	8.80	40.	1.8*	50.*
52	18.0	8.80	70.	1.8*	50.*
53	18.0	8.80	76.	2.0*	56.
54	18.0	8.80	90.	2.4*	76.
55	18.0	8.80	95.	2.6*	86.
56	18.0	8.80	98.	2.7*	95.
57	26.0	13.0	25.	1.8*	50.*
58	26.0	13.0	40.	1.8*	50.*
59	26.0	13.0	70.	1.8*	50.*
60	26.0	13.0	76.	1.9*	55.
61	26.0	13.0	90.	2.4*	75.
62	26.0	13.0	95.	2.5*	85.
63	26.0	13.0	98.	2.7*	94.
64	51.0	27.0	25.	1.8*	50.*
65	51.0	27.0	40.	1.8*	50.*
66	51.0	27.0	70.	1.8*	50.*
67	51.0	27.0	76.	1.9*	54.
68	51.0	27.0	90.	2.3*	74.
69	51.0	27.0	95.	2.5*	84.
70	51.0	27.0	98.	2.7*	92.
71	210.	120.	25.	1.8*	50.*
72	210.	120.	40.	1.8*	50.*
73	210.	120.	70.	1.8*	50.*
74	210.	120.	76.	1.9*	53.
75	210.	120.	90.	2.3*	72.
76	210.	120.	95.	2.5*	81.
77	210.	120.	98.	2.6	88.
78	430.	270.	25.	1.8*	50.*
79	430.	270.	40.	1.8*	50.*
80	430.	270.	70.	1.8*	50.*
81	430.	270.	76.	1.9*	51.
82	430.	270.	90.	2.3*	70.
83	430.	270.	95.	2.4*	80.
84	430.	270.	98.	2.6	81.

* Design parameter held to limiting value.

Ethylbenzene

Table 3 (continued)
ESTIMATED COST - March 1989

Design Number	Estimated Capital Costs				Operating Cost ($K Year-1)	Yearly Cost ($K Year-1)	Production Cost ($ Kgal-1)
	Process ($K)	Support ($K)	Indirect ($K)	Total ($K)			
31	90.	150.	160.	400.	46.	93.	0.05
32	96.	150.	160.	410.	47.	96.	0.05
33	110.	170.	180.	460.	51.	110.	0.06
34	230.	250.	320.	800.	76.	170.	0.09
35	250.	270.	340.	860.	81.	180.	0.10
36	140.	230.	240.	620.	79.	150.	0.05
37	150.	240.	260.	650.	82.	160.	0.05
38	180.	260.	290.	720.	87.	170.	0.05
39	370.	390.	500.	1300.	130.	280.	0.09
40	400.	420.	540.	1400.	140.	300.	0.09
41	210.	320.	340.	860.	120.	220.	0.05
42	220.	330.	360.	900.	120.	230.	0.05
43	260.	350.	400.	1000.	130.	250.	0.05
44	520.	550.	700.	1800.	190.	400.	0.08
45	570.	590.	760.	1900.	200.	430.	0.09
46	390.	560.	620.	1600.	240.	430.	0.04
47	420.	580.	650.	1600.	250.	440.	0.04
48	490.	630.	740.	1900.	260.	480.	0.05
49	1000.	1000.	1300.	3300.	390.	780.	0.08
50	1100.	1100.	1400.	3600.	420.	840.	0.09
51	1600.	1800.	2200.	5500.	1100.	1800.	0.04
52	1700.	1800.	2300.	5800.	1200.	1900.	0.04
53	1900.	2100.	2600.	6700.	1200.	2000.	0.05
54	3900.	3600.	4900.	12000.	1800.	3200.	0.07
55	4200.	3900.	5300.	13000.	1900.	3500.	0.08
56	3100.	3300.	4200.	11000.	2700.	3900.	0.04
57	3300.	3500.	4500.	11000.	2700.	4100.	0.04
58	3900.	3900.	5100.	13000.	2900.	4400.	0.04
59	7800.	7000.	9700.	24000.	4100.	7000.	0.07
60	8500.	7500.	11000.	27000.	4300.	7400.	0.08

Ethylbenzene

Table 2 (continued)
SYSTEM SIZE - March 1989

Design Number	Loadings		Air: Water Ratio	Mass Trans. Coef. (sec-1)	Number of Columns	Column Diameter (ft)	Packing Height (ft)	Air Flow (SCFM)	Air Pressure (inch H2O)
	Liquid (GPM ft-2)	Air (SCFM ft-2)							
31	30.	73.	18.	0.014	1.3	16.0	1.2	19000.	2.1
32	30.	73.	18.	0.014	1.3	16.0	2.0	19000.	2.1
33	30.	73.	18.	0.014	1.3	16.0	4.2	19000.	2.3
34	30.	89.	22.	0.014	1.3	16.0	18.	23000.	3.5
35	30.	93.	23.	0.014	1.3	16.0	21.	24000.	3.9
36	30.	73.	18.	0.014	2.1	16.0	1.2	31000.	2.1
37	30.	73.	18.	0.014	2.1	16.0	2.0	31000.	2.1
38	30.	73.	18.	0.014	2.1	16.0	4.2	31000.	2.3
39	30.	89.	22.	0.014	2.1	16.0	18.	37000.	3.5
40	30.	92.	23.	0.014	2.1	16.0	21.	38000.	3.8
41	30.	73.	18.	0.014	3.0	16.0	1.2	44000.	2.1
42	30.	73.	18.	0.014	3.0	16.0	2.0	44000.	2.1
43	30.	73.	18.	0.014	3.0	16.0	4.2	44000.	2.3
44	30.	88.	22.	0.014	3.0	16.0	18.	53000.	3.5
45	30.	91.	23.	0.014	3.0	16.0	21.	55000.	3.8
46	30.	73.	18.	0.014	5.9	16.0	1.2	87000.	2.1
47	30.	73.	18.	0.014	5.9	16.0	2.0	87000.	2.1
48	30.	73.	18.	0.014	5.9	16.0	4.2	87000.	2.3
49	30.	87.	22.	0.014	5.9	16.0	18.	100000.	3.5
50	30.	90.	22.	0.014	5.9	16.0	21.	110000.	3.8
51	30.	73.	18.	0.014	24.2	16.0	1.2	360000.	2.1
52	30.	73.	18.	0.014	24.2	16.0	2.0	360000.	2.1
53	30.	73.	18.	0.014	24.2	16.0	4.2	360000.	2.3
54	30.	85.	21.	0.014	24.2	16.0	18.	410000.	3.4
55	30.	88.	22.	0.014	24.2	16.0	21.	430000.	3.7
56	30.	73.	18.	0.014	49.5	16.0	1.2	730000.	2.1
57	30.	73.	18.	0.014	49.5	16.0	2.0	730000.	2.1
58	30.	73.	18.	0.014	49.5	16.0	4.2	730000.	2.3
59	30.	84.	21.	0.014	49.5	16.0	19.	840000.	3.4
60	30.	87.	22.	0.014	49.5	16.0	21.	870000.	3.7

Ethylbenzene

Table 1 (continued)
DESIGN CRITERIA - March 1989

Design Number	Plant Capacity (MGD)	Average Flow (MGD)	Removal Efficiency (%)	Cost Optimized Parameters	
				Stripping Fractor	Air Gradient (N m-2 m-1)
31	11.0	5.00	20.	2.3*	50.*
32	11.0	5.00	30.	2.3*	50.*
33	11.0	5.00	50.	2.3*	50.*
34	11.0	5.00	92.9	2.8*	68.
35	11.0	5.00	95.	2.9*	73.
36	18.0	8.80	20.	2.3*	50.*
37	18.0	8.80	30.	2.3*	50.*
38	18.0	8.80	50.	2.3*	50.*
39	18.0	8.80	92.9	2.8*	67.
40	18.0	8.80	95.	2.9*	72.
41	26.0	13.0	20.	2.3*	50.*
42	26.0	13.0	30.	2.3*	50.*
43	26.0	13.0	50.	2.3*	50.*
44	26.0	13.0	92.9	2.8*	67.
45	26.0	13.0	95.	2.9*	71.
46	51.0	27.0	20.	2.3*	50.*
47	51.0	27.0	30.	2.3*	50.*
48	51.0	27.0	50.	2.3*	50.*
49	51.0	27.0	92.9	2.8*	66.
50	51.0	27.0	95.	2.8*	69.
51	210.	120.	20.	2.3*	50.*
52	210.	120.	30.	2.3*	50.*
53	210.	120.	50.	2.3*	50.*
54	210.	120.	92.9	2.7*	63.
55	210.	120.	95.	2.8*	67.
56	430.	270.	20.	2.3*	50.*
57	430.	270.	30.	2.3*	50.*
58	430.	270.	50.	2.3*	50.*
59	430.	270.	92.9	2.7*	62.
60	430.	270.	95.	2.8*	66.

* Design parameter held to limiting value.

1,2-Dichloropropane

Table 1
DESIGN CRITERIA - March 1989

Design Number	Plant Capacity (MGD)	Average Flow (MGD)	Removal Efficiency (%)	Cost Optimized Parameters	
				Stripping Fractor	Air Gradient (N m-2 m-1)
1	0.024	0.006	50.	1.0*	93.
2	0.024	0.006	80.	1.6	170.
3	0.024	0.006	90.	2.0	150.
4	0.024	0.006	95.	2.3	140.
5	0.024	0.006	96.	2.4	140.
6	0.024	0.006	98.	2.6	130.
7	0.087	0.024	50.	1.2*	130.
8	0.087	0.024	80.	2.0	150.
9	0.087	0.024	90.	2.5	150.
10	0.087	0.024	95.	2.8	140.
11	0.087	0.024	96.	2.9	140.
12	0.087	0.024	98.	3.2	130.
13	0.270	0.086	50.	1.1*	110.
14	0.270	0.086	80.	1.8	150.
15	0.270	0.086	90.	2.2	140.
16	0.270	0.086	95.	2.5	140.
17	0.270	0.086	96.	2.6	130.
18	0.270	0.086	98.	2.8	130.
19	0.650	0.230	50.	1.1*	97.
20	0.650	0.230	80.	1.7	140.
21	0.650	0.230	90.	2.1	130.
22	0.650	0.230	95.	2.4	120.
23	0.650	0.230	96.	2.4	120.
24	0.650	0.230	98.	2.6	120.
25	1.80	0.700	50.	1.0*	86.
26	1.80	0.700	80.	1.6	120.
27	1.80	0.700	90.	2.0	110.
28	1.80	0.700	95.	2.2	110.
29	1.80	0.700	96.	2.3	100.
30	1.80	0.700	98.	2.5	100.
31	4.80	2.10	50.	0.9*	77.
32	4.80	2.10	80.	1.5	100.
33	4.80	2.10	90.	1.9	97.
34	4.80	2.10	95.	2.1	93.
35	4.80	2.10	96.	2.2	93.
36	4.80	2.10	98.	2.3	91.

* Design parameter held to limiting value.

Toluene

Table 3 (continued)
ESTIMATED COST - March 1989

Design Number	Estimated Capital Costs Process ($K)	Support ($K)	Indirect ($K)	Total ($K)	Operating Cost ($K Year-1)	Yearly Cost ($K Year-1)	Production Cost ($ Kgal-1)
37	98.	160.	170.	420.	48.	97.	0.05
38	100.	160.	170.	430.	49.	100.	0.05
39	120.	180.	200.	500.	53.	110.	0.06
40	170.	210.	240.	610.	61.	130.	0.07
41	270.	280.	360.	910.	86.	190.	0.11
42	300.	300.	390.	1000.	93.	210.	0.12
43	160.	240.	260.	650.	82.	160.	0.05
44	170.	240.	270.	680.	84.	160.	0.05
45	200.	270.	310.	770.	91.	180.	0.06
46	270.	320.	380.	970.	100.	220.	0.07
47	430.	440.	570.	1400.	150.	320.	0.10
48	480.	480.	630.	1600.	160.	350.	0.11
49	220.	330.	360.	910.	120.	230.	0.05
50	230.	340.	370.	950.	120.	230.	0.05
51	280.	370.	430.	1100.	130.	260.	0.05
52	380.	440.	540.	1400.	150.	310.	0.07
53	610.	620.	810.	2000.	220.	460.	0.10
54	680.	670.	890.	2200.	230.	500.	0.10
55	430.	580.	660.	1700.	250.	450.	0.05
56	450.	600.	690.	1700.	250.	460.	0.05
57	540.	670.	790.	2000.	280.	510.	0.05
58	720.	810.	1000.	2500.	320.	610.	0.06
59	1200.	1100.	1500.	3800.	440.	900.	0.09
60	1300.	1200.	1700.	4200.	480.	980.	0.10
61	1700.	1900.	2300.	5900.	1200.	1900.	0.04
62	1800.	1900.	2400.	6100.	1200.	1900.	0.04
63	2100.	2200.	2800.	7200.	1300.	2100.	0.05
64	2800.	2800.	3700.	9200.	1500.	2600.	0.06
65	4600.	4100.	5700.	14000.	2000.	3700.	0.08
66	5100.	4500.	6300.	16000.	2200.	4000.	0.09
67	3400.	3500.	4500.	11000.	2700.	4100.	0.04
68	3600.	3600.	4700.	12000.	2800.	4200.	0.04
69	4300.	4200.	5500.	14000.	3000.	4600.	0.05
70	5600.	5300.	7200.	18000.	3400.	5500.	0.06
71	9100.	8000.	11000.	28000.	4600.	7900.	0.08
72	10000.	8800.	12000.	31000.	4900.	8600.	0.09

Toluene

Table 2 (continued)
SYSTEM SIZE - March 1989

Design Number	Loadings		Air: Water Ratio	Mass Trans. Coef. (sec-1)	Number of Columns	Column Diameter (ft)	Packing Height (ft)	Air Flow (SCFM)	Air Pressure (inch H_2O)
	Liquid (GPM ft-2)	Air (SCFM ft-2)							
37	30.	73.	18.	0.015	1.3	16.0	2.2	19000.	2.1
38	30.	73.	18.	0.015	1.3	16.0	2.9	19000.	2.2
39	30.	73.	18.	0.015	1.3	16.0	5.6	19000.	2.4
40	30.	76.	19.	0.015	1.3	16.0	11.	19000.	2.7
41	30.	98.	24.	0.015	1.3	16.0	23.	25000.	4.2
42	30.	100.	25.	0.015	1.3	16.0	26.	26000.	4.7
43	30.	73.	18.	0.015	2.1	16.0	2.2	31000.	2.1
44	30.	73.	18.	0.015	2.1	16.0	2.9	31000.	2.2
45	30.	73.	18.	0.015	2.1	16.0	5.6	31000.	2.4
46	30.	75.	19.	0.015	2.1	16.0	11.	31000.	2.7
47	30.	97.	24.	0.015	2.1	16.0	23.	41000.	4.2
48	30.	100.	25.	0.015	2.1	16.0	26.	42000.	4.7
49	30.	73.	18.	0.015	3.0	16.0	2.2	44000.	2.1
50	30.	73.	18.	0.015	3.0	16.0	2.9	44000.	2.2
51	30.	73.	18.	0.015	3.0	16.0	5.6	44000.	2.4
52	30.	75.	18.	0.015	3.0	16.0	11.	45000.	2.7
53	30.	97.	24.	0.015	3.0	16.0	23.	58000.	4.2
54	30.	100.	25.	0.015	3.0	16.0	26.	60000.	4.7
55	30.	73.	18.	0.015	5.9	16.0	2.2	87000.	2.1
56	30.	73.	18.	0.015	5.9	16.0	2.9	87000.	2.2
57	30.	73.	18.	0.015	5.9	16.0	5.6	87000.	2.4
58	30.	74.	18.	0.015	5.9	16.0	11.	87000.	2.7
59	30.	95.	24.	0.015	5.9	16.0	23.	110000.	4.2
60	30.	98.	24.	0.015	5.9	16.0	27.	120000.	4.6
61	30.	73.	18.	0.015	24.2	16.0	2.2	360000.	2.1
62	30.	73.	18.	0.015	24.2	16.0	2.9	360000.	2.2
63	30.	73.	18.	0.015	24.2	16.0	5.6	360000.	2.4
64	30.	73.	18.	0.015	24.2	16.0	11.	360000.	2.7
65	30.	94.	23.	0.015	24.2	16.0	23.	460000.	4.1
66	30.	97.	24.	0.015	24.2	16.0	27.	470000.	4.6
67	30.	73.	18.	0.015	49.5	16.0	2.2	730000.	2.1
68	30.	73.	18.	0.015	49.5	16.0	2.9	730000.	2.2
69	30.	73.	18.	0.015	49.5	16.0	5.6	730000.	2.4
70	30.	73.	18.	0.015	49.5	16.0	11.	730000.	2.7
71	30.	92.	23.	0.015	49.5	16.0	23.	920000.	4.1
72	30.	95.	24.	0.015	49.5	16.0	27.	950000.	4.5

Toluene

Table 1 (continued)
DESIGN CRITERIA - March 1989

Design Number	Plant Capacity (MGD)	Average Flow (MGD)	Removal Efficiency (%)	Cost Optimized Parameters	
				Stripping Fractor	Air Gradient (N m-2 m-1)
37	11.0	5.00	33.	2.2*	50.*
38	11.0	5.00	40.	2.2*	50.*
39	11.0	5.00	60.	2.2*	50.*
40	11.0	5.00	80.	2.2*	53.
41	11.0	5.00	96.7	2.9*	80.
42	11.0	5.00	98.	3.0*	85.
43	18.0	8.80	33.	2.2*	50.*
44	18.0	8.80	40.	2.2*	50.*
45	18.0	8.80	60.	2.2*	50.*
46	18.0	8.80	80.	2.2*	51.
47	18.0	8.80	96.7	2.9*	79.
48	18.0	8.80	98.	2.9*	83.
49	26.0	13.0	33.	2.2*	50.*
50	26.0	13.0	40.	2.2*	50.*
51	26.0	13.0	60.	2.2*	50.*
52	26.0	13.0	80.	2.2*	51.
53	26.0	13.0	96.7	2.8*	78.
54	26.0	13.0	98.	2.9*	82.
55	51.0	27.0	33.	2.2*	50.*
56	51.0	27.0	40.	2.2*	50.*
57	51.0	27.0	60.	2.2*	50.*
58	51.0	27.0	80.	2.2*	50.
59	51.0	27.0	96.7	2.8*	76.
60	51.0	27.0	98.	2.9*	80.
61	210.	120.	33.	2.2*	50.*
62	210.	120.	40.	2.2*	50.*
63	210.	120.	60.	2.2*	50.*
64	210.	120.	80.	2.2*	50.*
65	210.	120.	96.7	2.8*	74.
66	210.	120.	98.	2.8*	78.
67	430.	270.	33.	2.2*	50.*
68	430.	270.	40.	2.2*	50.*
69	430.	270.	60.	2.2*	50.*
70	430.	270.	80.	2.2*	50.*
71	430.	270.	96.7	2.7*	72.
72	430.	270.	98.	2.8*	76.

* Design parameter held to limiting value.

Tetrachloroethylene

Table 3 (continued)
ESTIMATED COST - March 1989

Design Number	Estimated Capital Costs Process ($K)	Support ($K)	Indirect ($K)	Total ($K)	Operating Cost ($K Year-1)	Yearly Cost ($K Year-1)	Production Cost ($ Kgal-1)
37	110.	160.	180.	450.	50.	100.	0.06
38	190.	220.	270.	690.	65.	150.	0.08
39	230.	250.	310.	790.	73.	170.	0.09
40	270.	290.	370.	930.	83.	190.	0.10
41	310.	310.	410.	1000.	91.	210.	0.12
42	390.	370.	500.	1300.	110.	260.	0.14
43	180.	250.	280.	710.	86.	170.	0.05
44	310.	350.	430.	1100.	110.	240.	0.07
45	360.	390.	500.	1300.	120.	270.	0.08
46	440.	450.	580.	1500.	140.	310.	0.10
47	490.	490.	650.	1600.	160.	350.	0.11
48	630.	590.	790.	2000.	190.	420.	0.13
49	250.	350.	390.	990.	130.	240.	0.05
50	430.	490.	600.	1500.	170.	340.	0.07
51	520.	550.	700.	1800.	180.	390.	0.08
52	620.	630.	820.	2100.	210.	450.	0.10
53	700.	690.	910.	2300.	230.	500.	0.10
54	890.	830.	1100.	2800.	270.	610.	0.13
55	480.	620.	720.	1800.	260.	480.	0.05
56	830.	890.	1100.	2800.	340.	670.	0.07
57	990.	1000.	1300.	3300.	380.	760.	0.08
58	1200.	1200.	1500.	3900.	430.	890.	0.09
59	1300.	1300.	1700.	4300.	470.	980.	0.10
60	1700.	1500.	2100.	5400.	560.	1200.	0.12
61	1900.	2000.	2600.	6500.	1200.	2000.	0.05
62	3200.	3100.	4100.	10000.	1600.	2800.	0.06
63	3800.	3600.	4800.	12000.	1700.	3200.	0.07
64	4600.	4200.	5800.	15000.	1900.	3700.	0.08
65	5200.	4600.	6500.	16000.	2100.	4000.	0.09
66	6600.	5700.	8000.	20000.	2500.	4900.	0.11
67	3800.	3800.	5000.	13000.	2900.	4300.	0.04
68	6400.	5900.	8100.	20000.	3600.	6000.	0.06
69	7700.	6900.	9500.	24000.	3900.	6800.	0.07
70	9200.	8100.	11000.	29000.	4400.	7800.	0.08
71	10000.	9100.	13000.	32000.	4800.	8600.	0.09
72	13000.	11000.	16000.	40000.	5600.	10000.	0.11

Tetrachloroethylene

Table 2 (continued)
SYSTEM SIZE - March 1989

Design Number	Loadings		Air: Water Ratio	Mass Trans. Coef. (sec-1)	Number of Columns	Column Diameter (ft)	Packing Height (ft)	Air Flow (SCFM)	Air Pressure (inch H2O)
	Liquid (GPM ft-2)	Air (SCFM ft-2)							
37	30.	73.	18.	0.015	1.3	16.0	3.7	19000.	2.2
38	30.	73.	18.	0.015	1.3	16.0	14.	19000.	2.9
39	30.	75.	19.	0.015	1.3	16.0	18.	19000.	3.2
40	30.	81.	20.	0.015	1.3	16.0	24.	21000.	3.7
41	30.	84.	21.	0.015	1.3	16.0	28.	21000.	4.1
42	30.	88.	22.	0.015	1.3	16.0	38.	22000.	5.1
43	30.	73.	18.	0.015	2.1	16.0	3.7	31000.	2.2
44	30.	73.	18.	0.015	2.1	16.0	14.	31000.	2.9
45	30.	74.	18.	0.015	2.1	16.0	18.	31000.	3.2
46	30.	80.	20.	0.015	2.1	16.0	24.	33000.	3.7
47	30.	83.	21.	0.015	2.1	16.0	28.	35000.	4.1
48	30.	87.	22.	0.015	2.1	16.0	38.	36000.	5.1
49	30.	73.	18.	0.015	3.0	16.0	3.7	44000.	2.2
50	30.	73.	18.	0.015	3.0	16.0	14.	44000.	2.9
51	30.	74.	18.	0.015	3.0	16.0	18.	44000.	3.1
52	30.	79.	20.	0.015	3.0	16.0	24.	48000.	3.7
53	30.	82.	21.	0.015	3.0	16.0	28.	50000.	4.1
54	30.	87.	22.	0.015	3.0	16.0	38.	52000.	5.1
55	30.	73.	18.	0.015	5.9	16.0	3.7	87000.	2.2
56	30.	73.	18.	0.015	5.9	16.0	14.	87000.	2.9
57	30.	73.	18.	0.015	5.9	16.0	18.	87000.	3.1
58	30.	79.	20.	0.015	5.9	16.0	24.	93000.	3.7
59	30.	81.	20.	0.015	5.9	16.0	29.	96000.	4.1
60	30.	86.	21.	0.015	5.9	16.0	39.	100000.	5.0
61	30.	73.	18.	0.015	24.2	16.0	3.7	360000.	2.2
62	30.	73.	18.	0.015	24.2	16.0	14.	360000.	2.9
63	30.	73.	18.	0.015	24.2	16.0	18.	360000.	3.1
64	30.	77.	19.	0.015	24.2	16.0	24.	370000.	3.6
65	30.	80.	20.	0.015	24.2	16.0	29.	390000.	4.0
66	30.	84.	21.	0.015	24.2	16.0	39.	410000.	4.9
67	30.	73.	18.	0.015	49.5	16.0	3.7	730000.	2.2
68	30.	73.	18.	0.015	49.5	16.0	14.	730000.	2.9
69	30.	73.	18.	0.015	49.5	16.0	18.	730000.	3.1
70	30.	76.	19.	0.015	49.5	16.0	24.	750000.	3.6
71	30.	79.	20.	0.015	49.5	16.0	29.	780000.	4.0
72	30.	83.	21.	0.015	49.5	16.0	39.	820000.	4.9

Tetrachloroethylene

Table 1 (continued)
DESIGN CRITERIA - March 1989

Design Number	Plant Capacity (MGD)	Average Flow (MGD)	Removal Efficiency (%)	Cost Optimized Parameters	
				Stripping Fractor	Air Gradient (N m-2 m-1)
37	11.0	5.00	50.	3.7*	50.*
38	11.0	5.00	90.	3.7*	50.*
39	11.0	5.00	95.	3.7*	51.
40	11.0	5.00	98.	4.0*	58.
41	11.0	5.00	99.	4.2*	62.
42	11.0	5.00	99.8	4.4*	67.
43	18.0	8.80	50.	3.7*	50.*
44	18.0	8.80	90.	3.7*	50.*
45	18.0	8.80	95.	3.7*	51.
46	18.0	8.80	98.	4.0*	57.
47	18.0	8.80	99.	4.1*	61.
48	18.0	8.80	99.8	4.3*	66.
49	26.0	13.0	50.	3.7*	50.*
50	26.0	13.0	90.	3.7*	50.*
51	26.0	13.0	95.	3.7*	50.
52	26.0	13.0	98.	3.9*	56.
53	26.0	13.0	99.	4.1*	60.
54	26.0	13.0	99.8	4.3*	65.
55	51.0	27.0	50.	3.7*	50.*
56	51.0	27.0	90.	3.7*	50.*
57	51.0	27.0	95.	3.7*	50.*
58	51.0	27.0	98.	3.9*	55.
59	51.0	27.0	99.	4.1*	59.
60	51.0	27.0	99.8	4.3*	64.
61	210.	120.	50.	3.7*	50.*
62	210.	120.	90.	3.7*	50.*
63	210.	120.	95.	3.7*	50.*
64	210.	120.	98.	3.8*	53.
65	210.	120.	99.	4.0*	57.
66	210.	120.	99.8	4.2*	62.
67	430.	270.	50.	3.7*	50.*
68	430.	270.	90.	3.7*	50.*
69	430.	270.	95.	3.7*	50.*
70	430.	270.	98.	3.8*	52.
71	430.	270.	99.	3.9*	55.
72	430.	270.	99.8	4.1*	60.

* Design parameter held to limiting value.

trans-1,2-Dichloroethylene

Table 3 (continued)
ESTIMATED COST - March 1989

Design Number	Estimated Capital Costs				Operating Cost ($K Year-1)	Yearly Cost ($K Year-1)	Production Cost ($ Kgal-1)
	Process ($K)	Support ($K)	Indirect ($K)	Total ($K)			
37	94.	150.	160.	410.	47.	95.	0.05
38	160.	200.	240.	600.	60.	130.	0.07
39	180.	220.	260.	650.	65.	140.	0.08
40	200.	230.	280.	710.	69.	150.	0.08
41	240.	260.	320.	820.	79.	170.	0.10
42	320.	320.	420.	1100.	100.	230.	0.12
43	150.	230.	250.	640.	81.	160.	0.05
44	260.	310.	370.	940.	100.	210.	0.07
45	290.	340.	410.	1000.	110.	230.	0.07
46	320.	360.	440.	1100.	120.	250.	0.08
47	380.	400.	510.	1300.	140.	290.	0.09
48	520.	510.	670.	1700.	170.	370.	0.12
49	220.	320.	350.	890.	120.	220.	0.05
50	370.	440.	520.	1300.	150.	310.	0.06
51	410.	470.	580.	1500.	160.	330.	0.07
52	450.	500.	620.	1600.	170.	360.	0.08
53	540.	560.	720.	1800.	200.	410.	0.09
54	730.	710.	950.	2400.	250.	530.	0.11
55	410.	570.	640.	1600.	250.	440.	0.04
56	700.	790.	970.	2500.	310.	600.	0.06
57	780.	850.	1100.	2700.	340.	650.	0.07
58	860.	910.	1200.	2900.	360.	710.	0.07
59	1000.	1000.	1400.	3400.	410.	810.	0.08
60	1400.	1300.	1800.	4500.	520.	1000.	0.11
61	1600.	1800.	2300.	5700.	1200.	1800.	0.04
62	2700.	2700.	3600.	9000.	1400.	2500.	0.06
63	3100.	3000.	3900.	10000.	1600.	2700.	0.06
64	3400.	3200.	4300.	11000.	1700.	2900.	0.07
65	4000.	3700.	5000.	13000.	1900.	3400.	0.08
66	5500.	4800.	6700.	17000.	2300.	4300.	0.10
67	3300.	3400.	4400.	11000.	2700.	4000.	0.04
68	5500.	5200.	7000.	18000.	3300.	5400.	0.05
69	6100.	5700.	7700.	20000.	3600.	5900.	0.06
70	6800.	6200.	8500.	21000.	3800.	6300.	0.06
71	8000.	7200.	9900.	25000.	4200.	7200.	0.07
72	11000.	9500.	13000.	34000.	5300.	9200.	0.09

trans-1,2-Dichloroethylene

Table 2 (continued)
SYSTEM SIZE - March 1989

Design Number	Loadings Liquid (GPM ft-2)	Loadings Air (SCFM ft-2)	Air: Water Ratio	Mass Trans. Coef. (sec-1)	Number of Columns	Column Diameter (ft)	Packing Height (ft)	Air Flow (SCFM)	Air Pressure (inch H2O)
37	30.	73.	18.	0.016	1.3	16.0	1.8	19000.	2.1
38	30.	78.	19.	0.016	1.3	16.0	9.9	20000.	2.7
39	30.	85.	21.	0.016	1.3	16.0	12.	22000.	3.0
40	30.	90.	23.	0.016	1.3	16.0	14.	23000.	3.2
41	30.	98.	24.	0.016	1.3	16.0	19.	25000.	3.8
42	30.	110.	27.	0.016	1.3	16.0	29.	27000.	5.3
43	30.	73.	18.	0.016	2.1	16.0	1.8	31000.	2.1
44	30.	77.	19.	0.016	2.1	16.0	10.	32000.	2.7
45	30.	84.	21.	0.016	2.1	16.0	12.	35000.	2.9
46	30.	89.	22.	0.016	2.1	16.0	14.	37000.	3.2
47	30.	97.	24.	0.016	2.1	16.0	19.	40000.	3.8
48	30.	110.	26.	0.016	2.1	16.0	29.	44000.	5.3
49	30.	73.	18.	0.016	3.0	16.0	1.8	44000.	2.1
50	30.	76.	19.	0.016	3.0	16.0	10.	46000.	2.7
51	30.	83.	21.	0.016	3.0	16.0	12.	50000.	2.9
52	30.	89.	22.	0.016	3.0	16.0	14.	53000.	3.2
53	30.	96.	24.	0.016	3.0	16.0	19.	58000.	3.8
54	30.	110.	26.	0.016	3.0	16.0	29.	63000.	5.2
55	30.	73.	18.	0.016	5.9	16.0	1.8	87000.	2.1
56	30.	76.	19.	0.016	5.9	16.0	10.	89000.	2.7
57	30.	83.	21.	0.016	5.9	16.0	12.	97000.	2.9
58	30.	88.	22.	0.016	5.9	16.0	14.	100000.	3.2
59	30.	95.	24.	0.016	5.9	16.0	19.	110000.	3.8
60	30.	100.	26.	0.016	5.9	16.0	29.	120000.	5.2
61	30.	73.	18.	0.016	24.2	16.0	1.8	360000.	2.1
62	30.	74.	18.	0.016	24.2	16.0	10.	360000.	2.6
63	30.	81.	20.	0.016	24.2	16.0	12.	390000.	2.9
64	30.	86.	21.	0.016	24.2	16.0	15.	420000.	3.2
65	30.	93.	23.	0.016	24.2	16.0	19.	450000.	3.7
66	30.	100.	26.	0.016	24.2	16.0	29.	500000.	5.1
67	30.	73.	18.	0.016	49.5	16.0	1.8	730000.	2.1
68	30.	73.	18.	0.016	49.5	16.0	10.	730000.	2.6
69	30.	80.	20.	0.016	49.5	16.0	13.	800000.	2.9
70	30.	85.	21.	0.016	49.5	16.0	15.	840000.	3.1
71	30.	92.	23.	0.016	49.5	16.0	19.	920000.	3.7
72	29.	100.	25.	0.016	50.3	16.0	29.	1000000.	5.0

trans-1,2-Dichloroethylene

Table 1 (continued)
DESIGN CRITERIA - March 1989

Design Number	Plant Capacity (MGD)	Average Flow (MGD)	Removal Efficiency (%)	Cost Optimized Parameters	
				Stripping Fractor	Air Gradient (N m-2 m-1)
37	11.0	5.00	30.	2.0*	50.*
38	11.0	5.00	80.	2.1*	55.
39	11.0	5.00	86.	2.3*	63.
40	11.0	5.00	90.	2.5*	70.
41	11.0	5.00	95.	2.7*	80.
42	11.0	5.00	99.	2.9*	93.
43	18.0	8.80	30.	2.0*	50.*
44	18.0	8.80	80.	2.1*	53.
45	18.0	8.80	86.	2.3*	62.
46	18.0	8.80	90.	2.4*	68.
47	18.0	8.80	95.	2.6*	78.
48	18.0	8.80	99.	2.9*	91.
49	26.0	13.0	30.	2.0*	50.*
50	26.0	13.0	80.	2.1*	53.
51	26.0	13.0	86.	2.3*	61.
52	26.0	13.0	90.	2.4*	67.
53	26.0	13.0	95.	2.6*	77.
54	26.0	13.0	99.	2.9*	91.
55	51.0	27.0	30.	2.0*	50.*
56	51.0	27.0	80.	2.0*	52.
57	51.0	27.0	86.	2.2*	60.
58	51.0	27.0	90.	2.4*	66.
59	51.0	27.0	95.	2.6*	76.
60	51.0	27.0	99.	2.8*	89.
61	210.	120.	30.	2.0*	50.*
62	210.	120.	80.	2.0*	50.
63	210.	120.	86.	2.2*	58.
64	210.	120.	90.	2.3*	64.
65	210.	120.	95.	2.5*	73.
66	210.	120.	99.	2.8*	86.
67	430.	270.	30.	2.0*	50.*
68	430.	270.	80.	2.0*	50.*
69	430.	270.	86.	2.2*	57.
70	430.	270.	90.	2.3*	63.
71	430.	270.	95.	2.5*	72.
72	430.	270.	99.	2.8	81.

* Design parameter held to limiting value.

Styrene

Table 3 (continued)
ESTIMATED COST - March 1989

Design Number	Estimated Capital Costs				Operating Cost ($K Year-1)	Yearly Cost ($K Year-1)	Production Cost ($ Kgal-1)
	Process ($K)	Support ($K)	Indirect ($K)	Total ($K)			
43	130.	180.	200.	520.	55.	120.	0.06
44	150.	190.	230.	570.	61.	130.	0.07
45	220.	240.	300.	760.	80.	170.	0.09
46	290.	300.	390.	970.	96.	210.	0.12
47	390.	370.	500.	1300.	120.	260.	0.14
48	440.	410.	550.	1400.	130.	290.	0.16
49	540.	480.	670.	1700.	150.	340.	0.19
50	210.	280.	320.	810.	95.	190.	0.06
51	240.	300.	350.	900.	100.	210.	0.07
52	350.	380.	480.	1200.	140.	280.	0.09
53	470.	470.	620.	1600.	160.	350.	0.11
54	630.	590.	800.	2000.	200.	440.	0.14
55	710.	650.	890.	2200.	220.	480.	0.15
56	870.	770.	1100.	2700.	250.	570.	0.18
57	300.	390.	450.	1100.	140.	270.	0.06
58	340.	420.	500.	1300.	150.	300.	0.06
59	500.	530.	670.	1700.	200.	400.	0.08
60	670.	660.	870.	2200.	240.	500.	0.10
61	900.	830.	1100.	2900.	290.	630.	0.13
62	1000.	920.	1300.	3200.	310.	690.	0.15
63	1200.	1100.	1500.	3800.	360.	810.	0.17
64	570.	690.	830.	2100.	290.	530.	0.05
65	660.	760.	930.	2300.	320.	590.	0.06
66	950.	980.	1300.	3200.	410.	790.	0.08
67	1300.	1200.	1700.	4200.	490.	980.	0.10
68	1700.	1600.	2200.	5400.	590.	1200.	0.12
69	1900.	1700.	2400.	6100.	640.	1400.	0.14
70	2400.	2100.	2900.	7300.	730.	1600.	0.16
71	2300.	2300.	3000.	7600.	1300.	2200.	0.05
72	2600.	2600.	3400.	8500.	1500.	2500.	0.06
73	3800.	3500.	4800.	12000.	1900.	3300.	0.07
74	5100.	4500.	6300.	16000.	2200.	4100.	0.09
75	6800.	5900.	8300.	21000.	2600.	5100.	0.12
76	7700.	6500.	9300.	24000.	2800.	5600.	0.13
77	9400.	7900.	11000.	29000.	3200.	6600.	0.15
78	4500.	4400.	5800.	15000.	3100.	4800.	0.05
79	5200.	4900.	6600.	17000.	3400.	5300.	0.05
80	7600.	6800.	9500.	24000.	4200.	7000.	0.07
81	10000.	8900.	13000.	32000.	4900.	8700.	0.09
82	14000.	12000.	17000.	42000.	5800.	11000.	0.11
83	16000.	13000.	19000.	47000.	6300.	12000.	0.12
84	19000.	16000.	23000.	58000.	7100.	14000.	0.14

Styrene

Table 2 (continued)
SYSTEM SIZE - March 1989

Design Number	Loadings		Air: Water Ratio	Mass Trans. Coef. (sec-1)	Number of Columns	Column Diameter (ft)	Packing Height (ft)	Air Flow (SCFM)	Air Pressure (inch H2O)
	Liquid (GPM ft-2)	Air (SCFM ft-2)							
43	30.	84.	21.	0.012	1.3	16.0	6.1	21000.	2.5
44	30.	100.	25.	0.013	1.3	16.0	8.1	25000.	2.8
45	28.	130.	33.	0.013	1.3	16.0	14.	34000.	4.0
46	24.	130.	40.	0.011	1.5	16.0	19.	41000.	4.5
47	22.	140.	46.	0.011	1.7	16.0	25.	47000.	5.2
48	21.	140.	49.	0.010	1.8	16.0	29.	50000.	5.6
49	20.	140.	52.	0.0099	1.9	16.0	35.	53000.	6.3
50	30.	84.	21.	0.012	2.1	16.0	6.2	35000.	2.5
51	30.	99.	25.	0.013	2.1	16.0	8.1	41000.	2.8
52	28.	120.	33.	0.012	2.2	16.0	14.	55000.	3.9
53	24.	130.	40.	0.011	2.6	16.0	19.	67000.	4.4
54	22.	130.	46.	0.010	2.9	16.0	25.	77000.	5.1
55	21.	130.	49.	0.010	3.0	16.0	28.	81000.	5.4
56	20.	140.	52.	0.0098	3.2	16.0	35.	87000.	6.1
57	30.	84.	21.	0.012	3.0	16.0	6.2	50000.	2.5
58	30.	98.	24.	0.013	3.0	16.0	8.2	59000.	2.8
59	28.	120.	33.	0.012	3.3	16.0	14.	80000.	3.9
60	24.	130.	40.	0.011	3.8	16.0	19.	97000.	4.3
61	21.	130.	46.	0.010	4.2	16.0	25.	110000.	5.0
62	21.	130.	49.	0.010	4.4	16.0	28.	120000.	5.3
63	19.	140.	52.	0.0097	4.6	16.0	35.	130000.	6.0
64	30.	83.	21.	0.012	5.9	16.0	6.2	97000.	2.5
65	30.	98.	24.	0.013	5.9	16.0	8.2	120000.	2.8
66	27.	120.	33.	0.012	6.5	16.0	14.	160000.	3.8
67	23.	130.	40.	0.011	7.5	16.0	19.	190000.	4.2
68	21.	130.	46.	0.010	8.4	16.0	25.	220000.	4.8
69	20.	130.	49.	0.0099	8.7	16.0	28.	230000.	5.1
70	19.	130.	52.	0.0096	9.2	16.0	34.	250000.	5.7
71	30.	81.	20.	0.012	24.2	16.0	6.3	390000.	2.5
72	30.	96.	24.	0.013	24.2	16.0	8.3	470000.	2.8
73	26.	120.	33.	0.012	27.5	16.0	14.	640000.	3.6
74	23.	120.	40.	0.011	31.9	16.0	19.	780000.	4.0
75	20.	130.	46.	0.0099	35.7	16.0	25.	900000.	4.6
76	20.	130.	49.	0.0097	37.1	16.0	28.	950000.	4.9
77	18.	130.	52.	0.0093	39.2	16.0	34.	1000000.	5.4
78	30.	81.	20.	0.012	49.5	16.0	6.3	800000.	2.5
79	30.	95.	24.	0.013	49.5	16.0	8.4	940000.	2.8
80	26.	110.	33.	0.012	58.0	16.0	14.	1300000.	3.5
81	22.	120.	40.	0.011	67.2	16.0	19.	1600000.	3.9
82	20.	120.	46.	0.0097	75.2	16.0	25.	1900000.	4.4
83	19.	120.	49.	0.0095	78.2	16.0	28.	1900000.	4.6
84	18.	130.	52.	0.0091	82.8	16.0	34.	2100000.	5.2

Styrene

Table 1 (continued)
DESIGN CRITERIA - March 1989

Design Number	Plant Capacity (MGD)	Average Flow (MGD)	Removal Efficiency (%)	Cost Optimized Parameters	
				Stripping Fractor	Air Gradient (N m-2 m-1)
43	11.0	5.00	50.	1.0*	62.
44	11.0	5.00	60.	1.1*	82.
45	11.0	5.00	80.	1.5	120.
46	11.0	5.00	90.	1.8	110.
47	11.0	5.00	96.	2.1	100.
48	11.0	5.00	97.5	2.2	100.
49	11.0	5.00	99.	2.4	100.
50	18.0	8.80	50.	0.9*	62.
51	18.0	8.80	60.	1.1*	81.
52	18.0	8.80	80.	1.5	110.
53	18.0	8.80	90.	1.8	100.
54	18.0	8.80	96.	2.1	99.
55	18.0	8.80	97.5	2.2	97.
56	18.0	8.80	99.	2.4	95.
57	26.0	13.0	50.	0.9*	61.
58	26.0	13.0	60.	1.1*	80.
59	26.0	13.0	80.	1.5	110.
60	26.0	13.0	90.	1.8	99.
61	26.0	13.0	96.	2.1	96.
62	26.0	13.0	97.5	2.2	95.
63	26.0	13.0	99.	2.4	93.
64	51.0	27.0	50.	0.9*	60.
65	51.0	27.0	60.	1.1*	79.
66	51.0	27.0	80.	1.5	100.
67	51.0	27.0	90.	1.8	95.
68	51.0	27.0	96.	2.1	92.
69	51.0	27.0	97.5	2.2	90.
70	51.0	27.0	99.	2.4	89.
71	210.	120.	50.	0.9*	59.
72	210.	120.	60.	1.1*	77.
73	210.	120.	80.	1.5	93.
74	210.	120.	90.	1.8	88.
75	210.	120.	96.	2.1	84.
76	210.	120.	97.5	2.2	83.
77	210.	120.	99.	2.4	82.
78	430.	270.	50.	0.9*	58.
79	430.	270.	60.	1.1*	76.
80	430.	270.	80.	1.5	86.
81	430.	270.	90.	1.8	81.
82	430.	270.	96.	2.1	78.
83	430.	270.	97.5	2.2	77.
84	430.	270.	99.	2.4	76.

* Design parameter held to limiting value.

p-Xylene

Table 3 (continued)
ESTIMATED COST - March 1989

Design Number	Estimated Capital Costs				Operating Cost ($K Year-1)	Yearly Cost ($K Year-1)	Production Cost ($ Kgal-1)
	Process ($K)	Support ($K)	Indirect ($K)	Total ($K)			
43	93.	150.	160.	410.	47.	94.	0.05
44	100.	160.	170.	440.	49.	100.	0.06
45	150.	190.	220.	560.	57.	120.	0.07
46	160.	200.	240.	600.	60.	130.	0.07
47	220.	240.	300.	760.	73.	160.	0.09
48	260.	270.	350.	880.	84.	190.	0.10
49	320.	320.	410.	1000.	98.	220.	0.12
50	150.	230.	250.	630.	81.	150.	0.05
51	170.	250.	270.	680.	84.	160.	0.05
52	230.	300.	350.	880.	98.	200.	0.06
53	260.	310.	370.	950.	100.	210.	0.07
54	350.	380.	470.	1200.	130.	270.	0.08
55	410.	430.	550.	1400.	140.	310.	0.10
56	510.	500.	660.	1700.	170.	360.	0.11
57	210.	320.	350.	880.	120.	220.	0.05
58	240.	340.	380.	960.	120.	240.	0.05
59	330.	410.	490.	1200.	140.	290.	0.06
60	370.	440.	530.	1300.	150.	310.	0.06
61	490.	530.	670.	1700.	180.	380.	0.08
62	590.	600.	780.	2000.	210.	440.	0.09
63	720.	700.	930.	2400.	250.	520.	0.11
64	410.	570.	640.	1600.	240.	430.	0.04
65	460.	600.	690.	1800.	260.	460.	0.05
66	640.	740.	900.	2300.	300.	570.	0.06
67	700.	790.	980.	2500.	310.	600.	0.06
68	940.	970.	1300.	3200.	380.	750.	0.08
69	1100.	1100.	1500.	3700.	440.	870.	0.09
70	1400.	1300.	1800.	4400.	510.	1000.	0.10
71	1600.	1800.	2200.	5700.	1200.	1800.	0.04
72	1800.	2000.	2500.	6200.	1200.	1900.	0.04
73	2500.	2500.	3300.	8300.	1400.	2400.	0.05
74	2700.	2700.	3600.	9000.	1400.	2500.	0.06
75	3700.	3400.	4600.	12000.	1700.	3100.	0.07
76	4400.	4000.	5500.	14000.	2000.	3600.	0.08
77	5400.	4700.	6600.	17000.	2300.	4300.	0.10
78	3200.	3400.	4300.	11000.	2700.	4000.	0.04
79	3600.	3700.	4800.	12000.	2800.	4200.	0.04
80	5000.	4800.	6400.	16000.	3200.	5100.	0.05
81	5500.	5200.	7000.	18000.	3300.	5400.	0.05
82	7400.	6600.	9200.	23000.	4000.	6700.	0.07
83	8800.	7800.	11000.	27000.	4500.	7700.	0.08
84	11000.	9300.	13000.	33000.	5200.	9100.	0.09

p-Xylene

Table 2 (continued)
SYSTEM SIZE - March 1989

Design Number	Loadings		Air: Water Ratio	Mass Trans. Coef. (sec-1)	Number of Columns	Column Diameter (ft)	Packing Height (ft)	Air Flow (SCFM)	Air Pressure (inch H2O)
	Liquid (GPM ft-2)	Air (SCFM ft-2)							
43	30.	73.	18.	0.014	1.3	16.0	1.7	19000.	2.1
44	30.	73.	18.	0.014	1.3	16.0	3.1	19000.	2.2
45	30.	73.	18.	0.014	1.3	16.0	8.3	19000.	2.5
46	30.	76.	19.	0.014	1.3	16.0	10.	19000.	2.7
47	30.	92.	23.	0.014	1.3	16.0	16.	23000.	3.5
48	30.	100.	25.	0.014	1.3	16.0	21.	25000.	4.2
49	30.	110.	26.	0.014	1.3	16.0	28.	27000.	5.1
50	30.	73.	18.	0.014	2.1	16.0	1.7	31000.	2.1
51	30.	73.	18.	0.014	2.1	16.0	3.1	31000.	2.2
52	30.	73.	18.	0.014	2.1	16.0	8.3	31000.	2.5
53	30.	75.	19.	0.014	2.1	16.0	10.	31000.	2.7
54	30.	91.	23.	0.014	2.1	16.0	17.	38000.	3.4
55	30.	99.	25.	0.014	2.1	16.0	21.	41000.	4.1
56	30.	100.	26.	0.014	2.1	16.0	28.	43000.	5.1
57	30.	73.	18.	0.014	3.0	16.0	1.7	44000.	2.1
58	30.	73.	18.	0.014	3.0	16.0	3.1	44000.	2.2
59	30.	73.	18.	0.014	3.0	16.0	8.3	44000.	2.5
60	30.	75.	19.	0.014	3.0	16.0	10.	45000.	2.6
61	30.	91.	23.	0.014	3.0	16.0	17.	54000.	3.4
62	30.	98.	24.	0.014	3.0	16.0	22.	59000.	4.1
63	30.	100.	26.	0.014	3.0	16.0	28.	62000.	5.1
64	30.	73.	18.	0.014	5.9	16.0	1.7	87000.	2.1
65	30.	73.	18.	0.014	5.9	16.0	3.1	87000.	2.2
66	30.	73.	18.	0.014	5.9	16.0	8.3	87000.	2.5
67	30.	74.	18.	0.014	5.9	16.0	10.	87000.	2.6
68	30.	90.	22.	0.014	5.9	16.0	17.	110000.	3.4
69	30.	97.	24.	0.014	5.9	16.0	22.	110000.	4.1
70	30.	100.	26.	0.014	5.9	16.0	29.	120000.	5.0
71	30.	73.	18.	0.014	24.2	16.0	1.7	360000.	2.1
72	30.	73.	18.	0.014	24.2	16.0	3.1	360000.	2.2
73	30.	73.	18.	0.014	24.2	16.0	8.3	360000.	2.5
74	30.	73.	18.	0.014	24.2	16.0	10.	360000.	2.6
75	30.	88.	22.	0.014	24.2	16.0	17.	430000.	3.4
76	30.	95.	24.	0.014	24.2	16.0	22.	460000.	4.0
77	30.	100.	25.	0.014	24.2	16.0	29.	490000.	5.0
78	30.	73.	18.	0.014	49.5	16.0	1.7	730000.	2.1
79	30.	73.	18.	0.014	49.5	16.0	3.1	730000.	2.2
80	30.	73.	18.	0.014	49.5	16.0	8.3	730000.	2.5
81	30.	73.	18.	0.014	49.5	16.0	10.	730000.	2.6
82	30.	87.	22.	0.014	49.5	16.0	17.	860000.	3.4
83	30.	94.	23.	0.014	49.5	16.0	22.	930000.	4.0
84	30.	99.	25.	0.014	49.5	16.0	29.	990000.	4.9

p-Xylene

Table 1 (continued)
DESIGN CRITERIA - March 1989

Design Number	Plant Capacity (MGD)	Average Flow (MGD)	Removal Efficiency (%)	Cost Optimized Parameters	
				Stripping Fractor	Air Gradient (N m-2 m-1)
43	11.0	5.00	25.	2.0*	50.*
44	11.0	5.00	40.	2.0*	50.*
45	11.0	5.00	70.	2.0*	50.*
46	11.0	5.00	76.	2.1*	53.
47	11.0	5.00	90.	2.5*	72.
48	11.0	5.00	95.	2.7*	82.
49	11.0	5.00	98.	2.9*	91.
50	18.0	8.80	25.	2.0*	50.*
51	18.0	8.80	40.	2.0*	50.*
52	18.0	8.80	70.	2.0*	50.*
53	18.0	8.80	76.	2.0*	51.
54	18.0	8.80	90.	2.5*	71.
55	18.0	8.80	95.	2.7*	81.
56	18.0	8.80	98.	2.8*	89.
57	26.0	13.0	25.	2.0*	50.*
58	26.0	13.0	40.	2.0*	50.*
59	26.0	13.0	70.	2.0*	50.*
60	26.0	13.0	76.	2.0*	51.
61	26.0	13.0	90.	2.5*	70.
62	26.0	13.0	95.	2.7*	80.
63	26.0	13.0	98.	2.8*	88.
64	51.0	27.0	25.	2.0*	50.*
65	51.0	27.0	40.	2.0*	50.*
66	51.0	27.0	70.	2.0*	50.*
67	51.0	27.0	76.	2.0*	50.
68	51.0	27.0	90.	2.4*	69.
69	51.0	27.0	95.	2.6*	78.
70	51.0	27.0	98.	2.8*	87.
71	210.	120.	25.	2.0*	50.*
72	210.	120.	40.	2.0*	50.*
73	210.	120.	70.	2.0*	50.*
74	210.	120.	76.	2.0*	50.*
75	210.	120.	90.	2.4*	67.
76	210.	120.	95.	2.6*	76.
77	210.	120.	98.	2.7*	83.
78	430.	270.	25.	2.0*	50.*
79	430.	270.	40.	2.0*	50.*
80	430.	270.	70.	2.0*	50.*
81	430.	270.	76.	2.0*	50.*
82	430.	270.	90.	2.4*	65.
83	430.	270.	95.	2.5*	74.
84	430.	270.	98.	2.7*	82.

* Design parameter held to limiting value.

o-Xylene

Table 3 (continued)
ESTIMATED COST - March 1989

Design Number	Estimated Capital Costs				Operating Cost ($K Year-1)	Yearly Cost ($K Year-1)	Production Cost ($ Kgal-1)
	Process ($K)	Support ($K)	Indirect ($K)	Total ($K)			
43	94.	150.	160.	410.	47.	95.	0.05
44	110.	160.	180.	440.	49.	100.	0.06
45	150.	200.	230.	570.	58.	130.	0.07
46	170.	210.	240.	620.	62.	130.	0.07
47	220.	250.	310.	780.	77.	170.	0.09
48	270.	280.	360.	920.	89.	200.	0.11
49	330.	330.	430.	1100.	110.	230.	0.13
50	150.	230.	250.	630.	81.	160.	0.05
51	170.	250.	270.	690.	85.	170.	0.05
52	240.	300.	360.	900.	100.	210.	0.06
53	270.	320.	380.	970.	110.	220.	0.07
54	360.	390.	490.	1200.	130.	280.	0.09
55	430.	440.	580.	1500.	150.	320.	0.10
56	530.	520.	690.	1700.	180.	390.	0.12
57	210.	320.	350.	890.	120.	220.	0.05
58	240.	340.	380.	970.	120.	240.	0.05
59	350.	420.	500.	1300.	150.	300.	0.06
60	380.	450.	540.	1400.	160.	320.	0.07
61	510.	550.	690.	1800.	190.	400.	0.08
62	620.	630.	810.	2100.	220.	470.	0.10
63	760.	730.	970.	2500.	270.	550.	0.12
64	410.	570.	640.	1600.	250.	440.	0.04
65	460.	610.	700.	1800.	260.	470.	0.05
66	660.	760.	930.	2400.	300.	580.	0.06
67	730.	810.	1000.	2500.	320.	620.	0.06
68	980.	1000.	1300.	3300.	400.	780.	0.08
69	1200.	1200.	1500.	3900.	460.	920.	0.09
70	1500.	1400.	1800.	4700.	540.	1100.	0.11
71	1600.	1800.	2300.	5700.	1200.	1800.	0.04
72	1800.	2000.	2500.	6300.	1200.	1900.	0.04
73	2600.	2600.	3400.	8600.	1400.	2400.	0.06
74	2800.	2800.	3700.	9300.	1500.	2600.	0.06
75	3800.	3500.	4800.	12000.	1800.	3300.	0.07
76	4600.	4200.	5700.	15000.	2100.	3800.	0.09
77	5700.	5000.	7100.	18000.	2400.	4500.	0.10
78	3300.	3400.	4400.	11000.	2700.	4000.	0.04
79	3700.	3700.	4800.	12000.	2800.	4300.	0.04
80	5200.	4900.	6600.	17000.	3300.	5200.	0.05
81	5700.	5300.	7200.	18000.	3400.	5600.	0.06
82	7700.	6900.	9500.	24000.	4200.	7000.	0.07
83	9300.	8200.	11000.	29000.	4700.	8100.	0.08
84	12000.	10000.	14000.	36000.	5400.	9600.	0.10

o-Xylene

Table 2 (continued)
SYSTEM SIZE - March 1989

Design Number	Loadings		Air: Water Ratio	Mass Trans. Coef. (sec-1)	Number of Columns	Column Diameter (ft)	Packing Height (ft)	Air Flow (SCFM)	Air Pressure (inch H20)
	Liquid (GPM ft-2)	Air (SCFM ft-2)							
43	30.	73.	18.	0.013	1.3	16.0	1.7	19000.	2.1
44	30.	73.	18.	0.013	1.3	16.0	3.3	19000.	2.2
45	30.	77.	19.	0.013	1.3	16.0	8.9	19000.	2.6
46	30.	84.	21.	0.014	1.3	16.0	10.	21000.	2.8
47	30.	100.	25.	0.014	1.3	16.0	17.	26000.	3.8
48	30.	110.	27.	0.014	1.3	16.0	23.	28000.	4.6
49	30.	110.	28.	0.014	1.3	16.0	30.	29000.	5.8
50	30.	73.	18.	0.013	2.1	16.0	1.7	31000.	2.1
51	30.	73.	18.	0.013	2.1	16.0	3.3	31000.	2.2
52	30.	76.	19.	0.013	2.1	16.0	8.9	32000.	2.6
53	30.	83.	21.	0.014	2.1	16.0	11.	35000.	2.8
54	30.	100.	25.	0.014	2.1	16.0	17.	42000.	3.8
55	30.	110.	27.	0.014	2.1	16.0	23.	45000.	4.6
56	30.	110.	28.	0.014	2.1	16.0	30.	47000.	5.8
57	30.	73.	18.	0.013	3.0	16.0	1.7	44000.	2.1
58	30.	73.	18.	0.013	3.0	16.0	3.3	44000.	2.2
59	30.	76.	19.	0.013	3.0	16.0	9.0	45000.	2.6
60	30.	83.	21.	0.014	3.0	16.0	11.	50000.	2.8
61	30.	99.	25.	0.014	3.0	16.0	17.	60000.	3.7
62	30.	110.	27.	0.014	3.0	16.0	23.	64000.	4.6
63	30.	110.	28.	0.014	3.0	16.0	30.	68000.	5.7
64	30.	73.	18.	0.013	5.9	16.0	1.7	87000.	2.1
65	30.	73.	18.	0.013	5.9	16.0	3.3	87000.	2.2
66	30.	75.	19.	0.013	5.9	16.0	9.0	88000.	2.6
67	30.	81.	20.	0.014	5.9	16.0	11.	96000.	2.8
68	30.	98.	24.	0.014	5.9	16.0	17.	120000.	3.7
69	30.	110.	26.	0.014	5.9	16.0	23.	120000.	4.6
70	29.	110.	28.	0.014	6.0	16.0	30.	130000.	5.5
71	30.	73.	18.	0.013	24.2	16.0	1.7	360000.	2.1
72	30.	73.	18.	0.013	24.2	16.0	3.3	360000.	2.2
73	30.	73.	18.	0.013	24.2	16.0	9.1	360000.	2.6
74	30.	80.	20.	0.014	24.2	16.0	11.	390000.	2.8
75	30.	97.	24.	0.014	24.2	16.0	18.	470000.	3.7
76	30.	100.	26.	0.014	24.2	16.0	23.	500000.	4.5
77	28.	110.	28.	0.013	25.6	16.0	29.	550000.	5.2
78	30.	73.	18.	0.013	49.5	16.0	1.7	730000.	2.1
79	30.	73.	18.	0.013	49.5	16.0	3.3	730000.	2.2
80	30.	73.	18.	0.013	49.5	16.0	9.1	730000.	2.6
81	30.	79.	20.	0.014	49.5	16.0	11.	790000.	2.8
82	30.	95.	24.	0.014	49.5	16.0	18.	950000.	3.7
83	29.	100.	26.	0.014	50.4	16.0	23.	1000000.	4.4
84	27.	100.	28.	0.013	54.1	16.0	29.	1100000.	4.9

o-Xylene

Table 1 (continued)
DESIGN CRITERIA - March 1989

Design Number	Plant Capacity (MGD)	Average Flow (MGD)	Removal Efficiency (%)	Cost Optimized Parameters	
				Stripping !Fractor	Air Gradient (N m-2 m-1)
43	11.0	5.00	25.	1.7*	50.*
44	11.0	5.00	40.	1.7*	50.*
45	11.0	5.00	70.	1.7*	53.
46	11.0	5.00	76.	1.9*	62.
47	11.0	5.00	90.	2.3*	84.
48	11.0	5.00	95.	2.5*	95.
49	11.0	5.00	98.	2.6*	100.
50	18.0	8.80	25.	1.7*	50.*
51	18.0	8.80	40.	1.7*	50.*
52	18.0	8.80	70.	1.7*	53.
53	18.0	8.80	76.	1.9*	61.
54	18.0	8.80	90.	2.3*	83.
55	18.0	8.80	95.	2.4*	93.
56	18.0	8.80	98.	2.6*	100.
57	26.0	13.0	25.	1.7*	50.*
58	26.0	13.0	40.	1.7*	50.*
59	26.0	13.0	70.	1.7*	52.
60	26.0	13.0	76.	1.9*	60.
61	26.0	13.0	90.	2.2*	82.
62	26.0	13.0	95.	2.4*	93.
63	26.0	13.0	98.	2.5	100.
64	51.0	27.0	25.	1.7*	50.*
65	51.0	27.0	40.	1.7*	50.*
66	51.0	27.0	70.	1.7*	51.
67	51.0	27.0	76.	1.8*	59.
68	51.0	27.0	90.	2.2*	80.
69	51.0	27.0	95.	2.4*	91.
70	51.0	27.0	98.	2.6	95.
71	210.	120.	25.	1.7*	50.*
72	210.	120.	40.	1.7*	50.*
73	210.	120.	70.	1.7*	50.*
74	210.	120.	76.	1.8*	57.
75	210.	120.	90.	2.2*	78.
76	210.	120.	95.	2.3*	88.
77	210.	120.	98.	2.6	87.
78	430.	270.	25.	1.7*	50.*
79	430.	270.	40.	1.7*	50.*
80	430.	270.	70.	1.7*	50.*
81	430.	270.	76.	1.8*	56.
82	430.	270.	90.	2.2*	76.
83	430.	270.	95.	2.3	83.
84	430.	270.	98.	2.6	81.

* Design parameter held to limiting value.

o-Dichlorobenzene

Table 3 (continued)
ESTIMATED COST - March 1989

Design Number	Estimated Capital Costs Process ($K)	Support ($K)	Indirect ($K)	Total ($K)	Operating Cost ($K Year-1)	Yearly Cost ($K Year-1)	Production Cost ($ Kgal-1)
37	100.	160.	170.	430.	53.	100.	0.06
38	110.	160.	180.	440.	55.	110.	0.06
39	130.	180.	200.	510.	61.	120.	0.07
40	150.	190.	220.	560.	65.	130.	0.07
41	430.	400.	550.	1400.	130.	290.	0.16
42	490.	440.	610.	1500.	140.	320.	0.17
43	160.	240.	270.	670.	92.	170.	0.05
44	170.	250.	270.	690.	94.	180.	0.05
45	210.	280.	320.	800.	100.	200.	0.06
46	240.	300.	350.	880.	110.	220.	0.07
47	700.	640.	880.	2200.	210.	480.	0.15
48	790.	710.	980.	2500.	230.	520.	0.16
49	230.	340.	370.	940.	140.	250.	0.05
50	240.	340.	380.	970.	140.	250.	0.05
51	300.	380.	440.	1100.	150.	280.	0.06
52	340.	410.	490.	1200.	160.	310.	0.07
53	1000.	910.	1300.	3200.	310.	680.	0.14
54	1100.	1000.	1400.	3500.	340.	750.	0.16
55	450.	600.	690.	1700.	280.	480.	0.05
56	470.	610.	710.	1800.	290.	500.	0.05
57	570.	690.	820.	2100.	320.	560.	0.06
58	650.	750.	920.	2300.	340.	610.	0.06
59	1900.	1700.	2400.	6000.	640.	1300.	0.14
60	2200.	1900.	2700.	6700.	690.	1500.	0.15
61	1800.	1900.	2400.	6200.	1300.	2000.	0.05
62	1900.	2000.	2500.	6400.	1300.	2100.	0.05
63	2300.	2300.	3000.	7500.	1500.	2300.	0.05
64	2600.	2500.	3400.	8500.	1600.	2600.	0.06
65	7600.	6500.	9200.	23000.	2800.	5500.	0.13
66	8500.	7200.	10000.	26000.	3000.	6100.	0.14
67	3600.	3600.	4800.	12000.	3000.	4400.	0.05
68	3800.	3800.	4900.	12000.	3100.	4600.	0.05
69	4500.	4400.	5800.	15000.	3400.	5100.	0.05
70	5200.	4900.	6600.	17000.	3600.	5500.	0.06
71	15000.	13000.	19000.	47000.	6200.	12000.	0.12
72	17000.	14000.	21000.	52000.	6700.	13000.	0.13

Estimated Equipment Size and Cost for Removal of Phase II SOCs from Drinking Water Via Packed Column Air Stripping

March 1989

Compound:

cis-1,2-Dichloroethylene

Henry's Coefficient = 0.067 at 12 Deg. C

U.S. Environmental Protection Agency
Office of Drinking Water
Technical Support Division
Cincinnati, Ohio 45268

cis-1,2-Dichloroethylene

Table 1
DESIGN CRITERIA - March 1989

Design Number	Plant Capacity (MGD)	Average Flow (MGD)	Removal Efficiency (%)	Cost Optimized Parameters	
				Stripping Fractor	Air Gradient (N m-2 m-1)
1	0.024	0.006	30.	1.1*	50.*
2	0.024	0.006	50.	1.2*	56.
3	0.024	0.006	65.	1.6*	87.
4	0.024	0.006	90.	2.2*	160.
5	0.024	0.006	95.	2.5	160.
6	0.024	0.006	97.5	2.7	150.
7	0.087	0.024	30.	1.1*	50.*
8	0.087	0.024	50.	1.1*	50.*
9	0.087	0.024	65.	1.3*	60.
10	0.087	0.024	90.	2.7	140.
11	0.087	0.024	95.	3.0	140.
12	0.087	0.024	97.5	3.3	140.
13	0.270	0.086	30.	1.1*	50.*
14	0.270	0.086	50.	1.3*	67.
15	0.270	0.086	65.	1.7*	100.
16	0.270	0.086	90.	2.4	150.
17	0.270	0.086	95.	2.7	140.
18	0.270	0.086	97.5	3.0	140.
19	0.650	0.230	30.	1.1*	50.*
20	0.650	0.230	50.	1.2*	59.
21	0.650	0.230	65.	1.6*	89.
22	0.650	0.230	90.	2.2	140.
23	0.650	0.230	95.	2.5	130.
24	0.650	0.230	97.5	2.7	120.
25	1.80	0.700	30.	1.1*	50.*
26	1.80	0.700	50.	1.1*	52.
27	1.80	0.700	65.	1.5*	78.
28	1.80	0.700	90.	2.1	120.
29	1.80	0.700	95.	2.4	110.
30	1.80	0.700	97.5	2.6	110.
31	4.80	2.10	30.	1.1*	50.*
32	4.80	2.10	50.	1.1*	50.*
33	4.80	2.10	65.	1.4*	70.
34	4.80	2.10	90.	2.0	100.
35	4.80	2.10	95.	2.2	98.
36	4.80	2.10	97.5	2.4	96.

* Design parameter held to limiting value.

cis-1,2-Dichloroethylene

Table 2
SYSTEM SIZE - March 1989

Design Number	Loadings		Air: Water Ratio	Mass Trans. Coef. (sec-1)	Number of Columns	Column Diameter (ft)	Packing Height (ft)	Air Flow (SCFM)	Air Pressure (inch H2O)
	Liquid (GPM ft-2)	Air (SCFM ft-2)							
1	30.	73.	18.	0.015	1.0	0.8	2.1	41.	2.1
2	30.	79.	20.	0.015	1.0	0.8	4.6	44.	2.3
3	30.	100.	26.	0.015	1.0	0.8	6.9	57.	2.7
4	30.	150.	36.	0.016	1.0	0.8	15.	81.	5.1
5	28.	150.	40.	0.015	1.0	0.9	19.	90.	5.8
6	26.	150.	44.	0.014	1.0	0.9	23.	99.	6.2
7	30.	73.	18.	0.015	1.0	1.6	2.1	150.	2.1
8	30.	73.	18.	0.015	1.0	1.6	4.8	150.	2.3
9	30.	83.	21.	0.015	1.0	1.6	7.8	170.	2.6
10	25.	150.	44.	0.014	1.0	1.7	14.	360.	4.4
11	23.	150.	50.	0.013	1.0	1.8	17.	400.	4.9
12	22.	160.	55.	0.013	1.0	1.9	20.	440.	5.4
13	30.	73.	18.	0.015	1.0	2.8	2.1	460.	2.1
14	30.	88.	22.	0.015	1.0	2.8	4.4	550.	2.4
15	30.	110.	28.	0.015	1.0	2.8	6.6	700.	2.8
16	28.	150.	39.	0.015	1.0	2.9	14.	980.	4.7
17	25.	150.	45.	0.014	1.0	3.1	18.	1100.	5.1
18	23.	150.	48.	0.013	1.0	3.2	22.	1200.	5.6
19	30.	73.	18.	0.015	1.0	4.4	2.1	1100.	2.1
20	30.	82.	20.	0.015	1.0	4.4	4.5	1200.	2.3
21	30.	100.	26.	0.015	1.0	4.4	6.8	1600.	2.8
22	28.	140.	36.	0.015	1.0	4.5	15.	2200.	4.5
23	25.	140.	41.	0.014	1.0	4.7	19.	2500.	5.0
24	24.	140.	45.	0.013	1.0	4.9	23.	2700.	5.4
25	30.	73.	18.	0.015	1.0	7.3	2.1	3100.	2.1
26	30.	75.	19.	0.015	1.0	7.3	4.7	3100.	2.3
27	30.	97.	24.	0.015	1.0	7.3	7.1	4000.	2.7
28	28.	130.	34.	0.015	1.0	7.5	15.	5700.	4.3
29	25.	130.	39.	0.014	1.0	7.9	19.	6500.	4.7
30	24.	130.	42.	0.013	1.0	8.2	23.	7000.	5.1
31	30.	73.	18.	0.015	1.0	11.9	2.1	8200.	2.1
32	30.	73.	18.	0.015	1.0	11.9	4.8	8200.	2.3
33	30.	91.	23.	0.015	1.0	11.9	7.4	10000.	2.6
34	27.	120.	33.	0.014	1.0	12.5	16.	15000.	4.0
35	25.	120.	37.	0.014	1.0	13.0	20.	16000.	4.4
36	23.	130.	40.	0.013	1.0	13.5	24.	18000.	4.8

cis-1,2-Dichloroethylene

Table 3
ESTIMATED COST - March 1989

Design Number	Estimated Capital Costs Process ($K)	Support ($K)	Indirect ($K)	Total ($K)	Operating Cost ($K Year-1)	Yearly Cost ($K Year-1)	Production Cost ($ Kgal-1)
1	2.1	6.7	5.8	15.	0.21	1.9	0.94
2	2.5	7.0	6.2	16.	0.23	2.1	1.01
3	2.9	7.3	6.7	17.	0.27	2.2	1.10
4	4.5	8.2	8.3	21.	0.40	2.9	1.40
5	5.5	8.7	9.3	24.	0.46	3.2	1.57
6	6.4	9.2	10.	26.	0.53	3.6	1.74
7	4.9	11.	10.	26.	0.63	3.7	0.42
8	5.7	11.	11.	28.	0.69	4.0	0.46
9	6.8	12.	12.	31.	0.78	4.4	0.51
10	9.9	14.	16.	39.	1.1	5.7	0.65
11	12.	15.	17.	44.	1.3	6.4	0.73
12	13.	16.	19.	48.	1.4	7.1	0.81
13	7.6	17.	16.	40.	1.3	6.0	0.19
14	9.2	17.	17.	44.	1.5	6.6	0.21
15	11.	18.	19.	48.	1.7	7.3	0.23
16	17.	22.	25.	64.	2.4	9.9	0.32
17	20.	24.	29.	73.	2.8	11.	0.36
18	23.	26.	32.	82.	3.1	13.	0.41
19	12.	24.	24.	60.	2.8	9.8	0.12
20	14.	26.	27.	67.	3.1	11.	0.13
21	17.	28.	30.	75.	3.5	12.	0.15
22	28.	35.	41.	100.	5.1	17.	0.20
23	34.	38.	47.	120.	5.9	20.	0.24
24	39.	42.	53.	130.	6.6	22.	0.27
25	22.	42.	42.	110.	7.3	20.	0.08
26	28.	46.	48.	120.	8.1	22.	0.09
27	33.	50.	55.	140.	9.2	25.	0.10
28	54.	64.	78.	200.	13.	36.	0.14
29	67.	72.	91.	230.	15.	42.	0.16
30	79.	81.	100.	260.	17.	48.	0.19
31	47.	81.	84.	210.	20.	45.	0.06
32	58.	89.	96.	240.	22.	51.	0.07
33	70.	98.	110.	280.	25.	58.	0.08
34	110.	130.	160.	400.	35.	83.	0.11
35	140.	150.	190.	480.	41.	97.	0.13
36	170.	170.	220.	550.	45.	110.	0.14

Estimated Equipment Size and Cost for
Removal of Phase II SOCs from Drinking Water
Via
Packed Column Air Stripping

March 1989

Compound:

Dibromochloropropane

Henry's Coefficient = 0.006 at 12 Deg. C

U.S. Environmental Protection Agency
Office of Drinking Water
Technical Support Division
Cincinnati, Ohio 45268

Dibromochloropropane

Table 1
DESIGN CRITERIA - March 1989

Design Number	Plant Capacity (MGD)	Average Flow (MGD)	Removal Efficiency (%)	Cost Optimized Parameters	
				Stripping Fractor	Air Gradient (N m-2 m-1)
1	0.024	0.006	50.	1.0	180.
2	0.024	0.006	80.	1.8	180.
3	0.024	0.006	90.	2.2	170.
4	0.024	0.006	95.	2.5	170.
5	0.024	0.006	96.	2.5	170.
6	0.024	0.006	98.	2.7	160.
7	0.024	0.006	99.	2.9	160.
8	0.024	0.006	99.5	3.0	160.
9	0.087	0.024	50.	1.0	170.
10	0.087	0.024	80.	1.6	160.
11	0.087	0.024	90.	1.9	150.
12	0.087	0.024	95.	2.2	150.
13	0.087	0.024	96.	2.2	140.
14	0.087	0.024	98.	2.4	140.
15	0.087	0.024	99.	2.5	140.
16	0.087	0.024	99.5	2.6	140.
17	0.270	0.086	50.	1.0	150.
18	0.270	0.086	80.	1.4	130.
19	0.270	0.086	90.	1.8	120.
20	0.270	0.086	95.	2.0	120.
21	0.270	0.086	96.	2.0	120.
22	0.270	0.086	98.	2.2	120.
23	0.270	0.086	99.	2.3	120.
24	0.270	0.086	99.5	2.4	120.
25	0.650	0.230	50.	1.0	140.
26	0.650	0.230	80.	1.4	110.
27	0.650	0.230	90.	1.7	110.
28	0.650	0.230	95.	1.9	100.
29	0.650	0.230	96.	1.9	110.
30	0.650	0.230	98.	2.1	100.
31	0.650	0.230	99.	2.2	100.
32	0.650	0.230	99.5	2.3	100.
33	1.80	0.700	50.	1.0	140.
34	1.80	0.700	80.	1.3	100.
35	1.80	0.700	90.	1.5	110.
36	1.80	0.700	95.	1.7	110.
37	1.80	0.700	96.	1.8	110.
38	1.80	0.700	98.	1.9	110.
39	1.80	0.700	99.	2.0	110.
40	1.80	0.700	99.5	2.1	110.

Dibromochloropropane

Table 1 (continued)
DESIGN CRITERIA - March 1989

Design Number	Plant Capacity (MGD)	Average Flow (MGD)	Removal Efficiency (%)	Cost Optimized Parameters	
				Stripping Fractor	Air Gradient (N m-2 m-1)
81	210.	120.	50.	1.0	120.
82	210.	120.	80.	1.2	85.
83	210.	120.	90.	1.5	80.
84	210.	120.	95.	1.7	79.
85	210.	120.	96.	1.7	79.
86	210.	120.	98.	1.8	78.
87	210.	120.	99.	1.9	78.
88	210.	120.	99.5	2.0	77.
89	430.	270.	50.	1.0	120.
90	430.	270.	80.	1.2	80.
91	430.	270.	90.	1.5	75.
92	430.	270.	95.	1.7	74.
93	430.	270.	96.	1.7	74.
94	430.	270.	98.	1.8	73.
95	430.	270.	99.	1.9	73.
96	430.	270.	99.5	2.0	73.

Dibromochloropropane

Table 2
SYSTEM SIZE - March 1989

Design Number	Loadings		Air: Water Ratio	Mass Trans. Coef. (sec-1)	Number of Columns	Column Diameter (ft)	Packing Height (ft)	Air Flow (SCFM)	Air Pressure (inch H2O)
	Liquid (GPM ft-2)	Air (SCFM ft-2)							
1	9.7	240.	190.	0.0039	1.0	1.5	6.1	410.	3.4
2	5.9	260.	330.	0.0029	1.0	1.9	12.	730.	4.5
3	4.8	260.	400.	0.0026	1.0	2.1	15.	890.	5.2
4	4.3	260.	450.	0.0024	1.0	2.2	19.	1000.	5.8
5	4.1	260.	470.	0.0023	1.0	2.3	20.	1000.	6.0
6	3.8	260.	500.	0.0022	1.0	2.4	23.	1100.	6.6
7	3.6	260.	530.	0.0021	1.0	2.4	27.	1200.	7.2
8	3.4	250.	550.	0.0021	1.0	2.5	30.	1200.	7.8
9	9.3	230.	180.	0.0038	1.0	2.9	6.1	1500.	3.3
10	6.3	240.	290.	0.0030	1.0	3.5	13.	2300.	4.5
11	5.1	240.	350.	0.0026	1.0	3.9	17.	2800.	5.1
12	4.5	240.	400.	0.0024	1.0	4.1	21.	3200.	5.7
13	4.4	240.	410.	0.0024	1.0	4.2	22.	3300.	5.9
14	4.1	240.	440.	0.0023	1.0	4.3	26.	3600.	6.4
15	3.8	240.	460.	0.0022	1.0	4.5	29.	3800.	7.0
16	3.7	240.	480.	0.0021	1.0	4.6	33.	3900.	7.6
17	9.0	220.	180.	0.0036	1.0	5.2	6.1	4600.	3.1
18	6.3	220.	260.	0.0029	1.0	6.2	14.	6600.	4.2
19	5.1	220.	320.	0.0026	1.0	6.9	18.	8100.	4.7
20	4.6	220.	360.	0.0024	1.0	7.2	22.	9100.	5.3
21	4.4	220.	370.	0.0023	1.0	7.3	23.	9400.	5.5
22	4.1	220.	400.	0.0022	1.0	7.6	27.	10000.	6.0
23	3.9	220.	420.	0.0022	1.0	7.9	31.	11000.	6.5
24	3.7	220.	440.	0.0021	1.0	8.0	35.	11000.	7.0
25	8.8	220.	180.	0.0035	1.0	8.1	6.1	11000.	3.1
26	6.2	210.	250.	0.0028	1.0	9.6	14.	15000.	4.0
27	5.1	210.	300.	0.0025	1.0	10.6	19.	18000.	4.5
28	4.5	210.	340.	0.0023	1.0	11.3	23.	21000.	5.0
29	4.4	210.	350.	0.0023	1.0	11.4	25.	21000.	5.2
30	4.1	210.	380.	0.0022	1.0	11.8	29.	23000.	5.7
31	3.9	210.	400.	0.0021	1.0	12.2	33.	24000.	6.2
32	3.7	210.	420.	0.0021	1.0	12.4	37.	25000.	6.7
33	8.7	210.	180.	0.0035	1.0	13.5	6.1	31000.	3.0
34	6.2	200.	240.	0.0028	1.0	16.0	15.	40000.	4.0
35	5.5	210.	280.	0.0027	1.1	16.0	21.	47000.	4.8
36	4.9	210.	310.	0.0025	1.3	16.0	26.	53000.	5.4
37	4.8	210.	320.	0.0024	1.3	16.0	27.	54000.	5.6
38	4.5	210.	350.	0.0023	1.4	16.0	32.	58000.	6.2
39	4.3	210.	360.	0.0023	1.4	16.0	36.	61000.	6.8
40	4.1	210.	380.	0.0022	1.5	16.0	41.	63000.	7.4

Dibromochloropropane

Table 2 (continued)
SYSTEM SIZE - March 1989

Design Number	Loadings		Air: Water Ratio	Mass Trans. Coef. (sec-1)	Number of Columns	Column Diameter (ft)	Packing Height (ft)	Air Flow (SCFM)	Air Pressure (inch H2O)
	Liquid (GPM ft-2)	Air (SCFM ft-2)							
81	8.3	210.	180.	0.0034	87.0	16.0	6.0	3600000.	2.9
82	6.0	180.	230.	0.0027	121.0	16.0	16.	4400000.	3.7
83	4.9	180.	270.	0.0024	147.3	16.0	21.	5300000.	4.1
84	4.4	180.	310.	0.0022	164.8	16.0	26.	6000000.	4.5
85	4.3	180.	320.	0.0022	169.4	16.0	28.	6200000.	4.7
86	4.0	180.	340.	0.0021	181.2	16.0	32.	6600000.	5.1
87	3.8	180.	360.	0.0020	190.4	16.0	37.	6900000.	5.5
88	3.7	180.	370.	0.0020	197.8	16.0	41.	7200000.	5.9
89	8.2	200.	180.	0.0034	180.0	16.0	6.0	7400000.	2.9
90	5.9	180.	220.	0.0026	253.2	16.0	16.	9000000.	3.6
91	4.8	170.	270.	0.0023	309.6	16.0	21.	11000000.	4.0
92	4.3	180.	310.	0.0022	346.6	16.0	26.	12000000.	4.4
93	4.2	180.	310.	0.0021	354.9	16.0	28.	13000000.	4.5
94	3.9	180.	340.	0.0021	381.0	16.0	32.	13000000.	4.9
95	3.7	180.	350.	0.0020	400.5	16.0	37.	14000000.	5.3
96	3.6	180.	370.	0.0019	416.1	16.0	41.	15000000.	5.7

Dibromochloropropane

Table 3
ESTIMATED COST - March 1989

Design Number	Estimated Capital Costs Process ($K)	Support ($K)	Indirect ($K)	Total ($K)	Operating Cost ($K Year-1)	Yearly Cost ($K Year-1)	Production Cost ($ Kgal-1)
1	5.4	8.9	9.4	24.	0.59	3.4	1.65
2	8.9	11.	13.	33.	0.94	4.8	2.35
3	11.	13.	16.	40.	1.2	5.8	2.85
4	14.	14.	18.	46.	1.4	6.9	3.35
5	15.	14.	19.	48.	1.5	7.2	3.51
6	17.	16.	22.	55.	1.7	8.2	3.99
7	20.	17.	24.	61.	2.0	9.1	4.46
8	22.	19.	27.	67.	2.2	10.	4.93
9	11.	15.	17.	42.	1.5	6.4	0.73
10	19.	20.	25.	63.	2.5	9.9	1.13
11	24.	23.	31.	79.	3.2	12.	1.42
12	30.	27.	37.	94.	3.9	15.	1.70
13	32.	28.	39.	99.	4.1	16.	1.79
14	38.	32.	45.	110.	4.7	18.	2.06
15	43.	35.	51.	130.	5.3	20.	2.33
16	48.	38.	57.	140.	5.9	23.	2.60
17	20.	24.	29.	73.	3.6	12.	0.39
18	38.	36.	48.	120.	6.2	21.	0.65
19	51.	45.	63.	160.	8.0	27.	0.85
20	64.	54.	77.	190.	9.9	33.	1.04
21	68.	56.	81.	210.	10.	35.	1.10
22	80.	65.	95.	240.	12.	40.	1.28
23	93.	73.	110.	270.	14.	46.	1.46
24	100.	81.	120.	310.	15.	52.	1.64
25	36.	41.	50.	130.	8.3	23.	0.28
26	71.	65.	89.	220.	14.	40.	0.48
27	97.	83.	120.	300.	18.	53.	0.63
28	120.	100.	150.	370.	22.	65.	0.78
29	130.	110.	150.	390.	23.	69.	0.82
30	150.	120.	180.	460.	27.	81.	0.97
31	180.	140.	210.	530.	31.	93.	1.11
32	200.	160.	240.	600.	34.	110.	1.25
33	77.	81.	100.	260.	23.	54.	0.21
34	160.	140.	190.	490.	37.	95.	0.37
35	220.	180.	260.	670.	50.	130.	0.50
36	280.	230.	340.	850.	62.	160.	0.63
37	300.	250.	360.	910.	65.	170.	0.67
38	370.	290.	430.	1100.	76.	200.	0.80
39	430.	340.	500.	1300.	87.	240.	0.92
40	490.	380.	570.	1400.	97.	270.	1.04

Dibromochloropropane

Table 3 (continued)
ESTIMATED COST - March 1989

Design Number	Estimated Capital Costs				Operating Cost ($K Year-1)	Yearly Cost ($K Year-1)	Production Cost ($ Kgal-1)
	Process ($K)	Support ($K)	Indirect ($K)	Total ($K)			
81	7200.	6100.	8700.	22000.	3500.	6100.	0.14
82	16000.	13000.	19000.	47000.	5300.	11000.	0.25
83	23000.	18000.	27000.	67000.	6800.	15000.	0.33
84	29000.	23000.	34000.	87000.	8200.	18000.	0.42
85	31000.	25000.	37000.	93000.	8700.	20000.	0.45
86	38000.	30000.	44000.	110000.	10000.	23000.	0.53
87	44000.	35000.	52000.	130000.	11000.	27000.	0.61
88	50000.	40000.	59000.	150000.	13000.	30000.	0.69
89	15000.	12000.	17000.	44000.	7800.	13000.	0.13
90	32000.	26000.	38000.	95000.	12000.	23000.	0.23
91	46000.	37000.	54000.	140000.	15000.	31000.	0.31
92	59000.	48000.	70000.	180000.	18000.	39000.	0.39
93	63000.	51000.	75000.	190000.	19000.	41000.	0.42
94	76000.	62000.	91000.	230000.	22000.	49000.	0.49
95	89000.	72000.	110000.	270000.	24000.	56000.	0.57
96	100000.	83000.	120000.	310000.	27000.	63000.	0.64

Estimated Equipment Size and Cost for
Removal of Phase II SOCs from Drinking Water
Via
Packed Column Air Stripping

March 1989

Compound:

Ethylene Dibromide (EDB)

Henry's Coefficient = 0.014 at 12 Deg. C

U.S. Environmental Protection Agency
Office of Drinking Water
Technical Support Division
Cincinnati, Ohio 45268

Ethylene Dibromide (EDB)

Table 1
DESIGN CRITERIA - March 1989

Design Number	Plant Capacity (MGD)	Average Flow (MGD)	Removal Efficiency (%)	Cost Optimized Parameters	
				Stripping Fractor	Air Gradient (N m-2 m-1)
1	0.024	0.006	90.	2.4	150.
2	0.024	0.006	98.	3.0	150.
3	0.024	0.006	99.5	3.4	140.
4	0.024	0.006	99.9	3.6	140.
5	0.024	0.006	99.98	3.8	140.
6	0.087	0.024	90.	2.1	150.
7	0.087	0.024	98.	2.6	140.
8	0.087	0.024	99.5	2.9	140.
9	0.087	0.024	99.9	3.1	120.
10	0.087	0.024	99.98	3.2	130.
11	0.270	0.086	90.	1.9	130.
12	0.270	0.086	98.	2.4	120.
13	0.270	0.086	99.5	2.6	120.
14	0.270	0.086	99.9	2.8	120.
15	0.270	0.086	99.98	2.9	110.
16	0.650	0.230	90.	1.8	110.
17	0.650	0.230	98.	2.2	110.
18	0.650	0.230	99.5	2.4	100.
19	0.650	0.230	99.9	2.6	100.
20	0.650	0.230	99.98	2.7	100.
21	1.80	0.700	90.	1.7	99.
22	1.80	0.700	98.	2.1	95.
23	1.80	0.700	99.5	2.3	93.
24	1.80	0.700	99.9	2.5	92.
25	1.80	0.700	99.98	2.6	91.
26	4.80	2.10	90.	1.6	100.
27	4.80	2.10	98.	1.9	99.
28	4.80	2.10	99.5	2.1	97.
29	4.80	2.10	99.9	2.3	96.
30	4.80	2.10	99.98	2.4	96.

Ethylene Dibromide (EDB)

Table 2
SYSTEM SIZE - March 1989

Design Number	Loadings		Air: Water Ratio	Mass Trans. Coef. (sec-1)	Number of Columns	Column Diameter (ft)	Packing Height (ft)	Air Flow (SCFM)	Air Pressure (inch H20)
	Liquid (GPM ft-2)	Air (SCFM ft-2)							
1	8.9	220.	190.	0.0052	1.0	1.5	13.	420.	4.4
2	7.2	230.	240.	0.0046	1.0	1.7	20.	530.	5.7
3	6.5	230.	260.	0.0043	1.0	1.8	26.	590.	6.7
4	6.1	230.	280.	0.0041	1.0	1.9	33.	630.	7.9
5	5.8	230.	300.	0.0039	1.0	1.9	40.	660.	9.0
6	10.	220.	160.	0.0057	1.0	2.8	14.	1300.	4.8
7	8.0	220.	210.	0.0049	1.0	3.1	23.	1700.	5.9
8	7.3	220.	230.	0.0046	1.0	3.2	29.	1800.	7.0
9	6.6	210.	240.	0.0042	1.0	3.4	36.	2000.	7.6
10	6.5	220.	260.	0.0042	1.0	3.4	44.	2100.	9.2
11	10.	200.	150.	0.0057	1.0	4.8	16.	3700.	4.6
12	8.2	200.	190.	0.0049	1.0	5.4	24.	4700.	5.6
13	7.5	210.	200.	0.0046	1.0	5.6	31.	5100.	6.6
14	7.0	210.	220.	0.0044	1.0	5.8	39.	5500.	7.6
15	6.7	210.	230.	0.0043	1.0	6.0	47.	5800.	8.6
16	10.	190.	140.	0.0055	1.0	7.5	16.	8400.	4.3
17	8.2	190.	170.	0.0049	1.0	8.4	25.	11000.	5.3
18	7.5	190.	190.	0.0046	1.0	8.8	33.	12000.	6.2
19	7.1	190.	200.	0.0044	1.0	9.0	41.	12000.	7.2
20	6.8	190.	210.	0.0043	1.0	9.2	49.	13000.	8.2
21	10.	180.	130.	0.0055	1.0	12.6	17.	22000.	4.1
22	8.2	180.	160.	0.0048	1.0	13.9	26.	27000.	5.1
23	7.5	180.	180.	0.0045	1.0	14.5	34.	30000.	5.9
24	7.1	180.	190.	0.0044	1.0	15.0	43.	32000.	6.8
25	6.8	180.	200.	0.0042	1.0	15.3	52.	34000.	7.8
26	11.	180.	120.	0.0057	1.5	16.0	18.	55000.	4.4
27	8.9	180.	150.	0.0051	1.9	16.0	28.	68000.	5.5
28	8.2	180.	170.	0.0048	2.0	16.0	37.	75000.	6.4
29	7.7	180.	180.	0.0046	2.1	16.0	46.	79000.	7.5
30	7.4	180.	190.	0.0045	2.2	16.0	56.	83000.	8.6

Ethylene Dibromide (EDB)

Table 3
ESTIMATED COST - March 1989

Design Number	Estimated Capital Costs Process ($K)	Support ($K)	Indirect ($K)	Total ($K)	Operating Cost ($K Year-1)	Yearly Cost ($K Year-1)	Production Cost ($ Kgal-1)
1	7.9	10.	12.	30.	0.76	4.3	2.10
2	11.	12.	15.	39.	1.1	5.7	2.77
3	14.	14.	18.	47.	1.3	6.8	3.32
4	18.	16.	22.	56.	1.6	8.1	3.96
5	21.	18.	25.	64.	1.8	9.4	4.58
6	16.	18.	22.	55.	1.9	8.4	0.96
7	23.	22.	30.	75.	2.7	12.	1.31
8	29.	26.	36.	92.	3.3	14.	1.61
9	37.	31.	44.	110.	3.9	17.	1.94
10	44.	35.	51.	130.	4.7	20.	2.27
11	30.	31.	40.	100.	4.5	16.	0.52
12	46.	41.	57.	140.	6.5	23.	0.75
13	59.	50.	71.	180.	8.1	29.	0.93
14	74.	60.	88.	220.	9.9	36.	1.15
15	90.	70.	100.	260.	12.	43.	1.35
16	54.	53.	70.	180.	9.8	31.	0.36
17	84.	73.	100.	260.	14.	45.	0.53
18	110.	91.	130.	330.	18.	57.	0.67
19	140.	110.	160.	410.	22.	70.	0.83
20	170.	130.	190.	490.	25.	83.	0.99
21	120.	110.	150.	370.	26.	69.	0.27
22	180.	160.	220.	570.	37.	100.	0.40
23	240.	200.	290.	730.	46.	130.	0.51
24	310.	250.	360.	920.	56.	160.	0.64
25	370.	290.	440.	1100.	66.	190.	0.76
26	270.	240.	340.	850.	72.	170.	0.22
27	440.	370.	530.	1300.	100.	260.	0.34
28	590.	480.	700.	1800.	130.	340.	0.44
29	750.	600.	880.	2200.	160.	420.	0.55
30	910.	720.	1100.	2700.	190.	510.	0.66

Estimated Equipment Size and Cost for
Removal of Phase II SOCs from Drinking Water
Via
Packed Column Air Stripping

March 1989

Compound:

Ethylbenzene

Henry's Coefficient = 0.14 at 12 Deg. C

U.S. Environmental Protection Agency
Office of Drinking Water
Technical Support Division
Cincinnati, Ohio 45268

1,2-Dichloropropane

Table 1 (continued)
DESIGN CRITERIA - March 1989

Design Number	Plant Capacity (MGD)	Average Flow (MGD)	Removal Efficiency (%)	Cost Optimized Parameters	
				Stripping Fractor	Air Gradient (N m-2 m-1)
37	11.0	5.00	50.	0.9*	74.
38	11.0	5.00	80.	1.5	110.
39	11.0	5.00	90.	1.8	100.
40	11.0	5.00	95.	2.0	100.
41	11.0	5.00	96.	2.0	100.
42	11.0	5.00	98.	2.2	100.
43	18.0	8.80	50.	0.9*	74.
44	18.0	8.80	80.	1.5	110.
45	18.0	8.80	90.	1.8	100.
46	18.0	8.80	95.	2.0	98.
47	18.0	8.80	96.	2.0	98.
48	18.0	8.80	98.	2.2	96.
49	26.0	13.0	50.	0.9*	74.
50	26.0	13.0	80.	1.5	100.
51	26.0	13.0	90.	1.8	99.
52	26.0	13.0	95.	2.0	96.
53	26.0	13.0	96.	2.0	96.
54	26.0	13.0	98.	2.2	94.
55	51.0	27.0	50.	0.9*	74.
56	51.0	27.0	80.	1.5	100.
57	51.0	27.0	90.	1.8	94.
58	51.0	27.0	95.	2.0	91.
59	51.0	27.0	96.	2.0	91.
60	51.0	27.0	98.	2.2	89.
61	210.	120.	50.	0.9*	74.
62	210.	120.	80.	1.4	92.
63	210.	120.	90.	1.8	87.
64	210.	120.	95.	2.0	84.
65	210.	120.	96.	2.0	83.
66	210.	120.	98.	2.2	82.
67	430.	270.	50.	0.9*	74.
68	430.	270.	80.	1.4	85.
69	430.	270.	90.	1.8	80.
70	430.	270.	95.	2.0	78.
71	430.	270.	96.	2.0	77.
72	430.	270.	98.	2.2	76.

* Design parameter held to limiting value.

1,2-Dichloropropane

Table 2 (continued)
SYSTEM SIZE - March 1989

Design Number	Loadings		Air: Water Ratio	Mass Trans. Coef. (sec-1)	Number of Columns	Column Diameter (ft)	Packing Height (ft)	Air Flow (SCFM)	Air Pressure (inch H2O)
	Liquid (GPM ft-2)	Air (SCFM ft-2)							
37	30.	94.	23.	0.013	1.3	16.0	6.1	24000.	2.6
38	26.	130.	37.	0.012	1.5	16.0	14.	38000.	3.9
39	22.	140.	45.	0.011	1.7	16.0	18.	46000.	4.4
40	21.	140.	51.	0.010	1.8	16.0	23.	52000.	4.9
41	20.	140.	52.	0.010	1.9	16.0	24.	53000.	5.1
42	19.	140.	56.	0.0098	2.0	16.0	29.	57000.	5.6
43	30.	94.	23.	0.013	2.1	16.0	6.1	39000.	2.6
44	26.	130.	37.	0.012	2.4	16.0	14.	62000.	3.8
45	22.	130.	45.	0.011	2.8	16.0	18.	76000.	4.3
46	20.	140.	51.	0.010	3.1	16.0	23.	85000.	4.8
47	20.	140.	52.	0.010	3.1	16.0	24.	87000.	4.9
48	19.	140.	56.	0.0097	3.3	16.0	29.	94000.	5.4
49	30.	94.	23.	0.013	3.0	16.0	6.1	56000.	2.6
50	25.	130.	37.	0.012	3.5	16.0	14.	90000.	3.8
51	22.	130.	45.	0.011	4.1	16.0	18.	110000.	4.2
52	20.	140.	51.	0.010	4.5	16.0	23.	120000.	4.7
53	20.	140.	52.	0.010	4.6	16.0	24.	130000.	4.9
54	19.	140.	56.	0.0096	4.8	16.0	29.	140000.	5.3
55	30.	94.	23.	0.013	5.9	16.0	6.1	110000.	2.6
56	25.	120.	37.	0.012	7.0	16.0	14.	180000.	3.7
57	22.	130.	45.	0.011	8.2	16.0	18.	210000.	4.1
58	20.	130.	51.	0.010	8.9	16.0	23.	240000.	4.6
59	19.	130.	52.	0.0098	9.1	16.0	24.	250000.	4.7
60	18.	140.	56.	0.0095	9.7	16.0	29.	270000.	5.2
61	30.	94.	23.	0.013	24.2	16.0	6.1	450000.	2.6
62	24.	120.	37.	0.011	29.9	16.0	14.	720000.	3.5
63	21.	130.	45.	0.010	34.6	16.0	18.	880000.	4.0
64	19.	130.	51.	0.0097	38.0	16.0	23.	990000.	4.4
65	19.	130.	52.	0.0096	38.9	16.0	24.	1000000.	4.5
66	18.	130.	56.	0.0092	41.1	16.0	29.	1100000.	4.9
67	30.	94.	23.	0.013	49.5	16.0	6.1	930000.	2.6
68	24.	120.	37.	0.011	62.9	16.0	14.	1500000.	3.4
69	20.	120.	45.	0.010	72.9	16.0	18.	1800000.	3.8
70	19.	130.	51.	0.0095	80.0	16.0	23.	2000000.	4.2
71	18.	130.	52.	0.0094	81.9	16.0	24.	2100000.	4.3
72	17.	130.	56.	0.0090	86.7	16.0	28.	2200000.	4.7

Estimated Equipment Size and Cost for Removal of Phase II SOCs from Drinking Water

Via

Packed Column Air Stripping

March 1989

Compound:

Toxaphene

Henry's Coefficient = 0.11 at 12 Deg. C

U.S. Environmental Protection Agency
Office of Drinking Water
Technical Support Division
Cincinnati, Ohio 45268

Toxaphene

Table 1
DESIGN CRITERIA - March 1989

Design Number	Plant Capacity (MGD)	Average Flow (MGD)	Removal Efficiency (%)	Cost Optimized Parameters	
				Stripping Fractor	Air Gradient (N m-2 m-1)
1	0.024	0.006	50.	1.8*	50.*
2	0.024	0.006	80.	2.7*	94.
3	0.024	0.006	90.	3.1*	120.
4	0.024	0.006	98.	3.4*	150.
5	0.087	0.024	50.	1.8*	50.*
6	0.087	0.024	80.	2.1*	65.
7	0.087	0.024	90.	3.3	130.
8	0.087	0.024	98.	4.1	120.
9	0.270	0.086	50.	1.9*	52.
10	0.270	0.086	80.	2.8*	100.
11	0.270	0.086	90.	3.1*	120.
12	0.270	0.086	98.	3.6	130.
13	0.650	0.230	50.	1.8*	50.*
14	0.650	0.230	80.	2.6*	91.
15	0.650	0.230	90.	2.9*	110.
16	0.650	0.230	98.	3.3	120.
17	1.80	0.700	50.	1.8*	50.*
18	1.80	0.700	80.	2.4*	80.
19	1.80	0.700	90.	2.7*	97.
20	1.80	0.700	98.	3.1	110.
21	4.80	2.10	50.	1.8*	50.*
22	4.80	2.10	80.	2.3*	71.
23	4.80	2.10	90.	2.6*	86.
24	4.80	2.10	98.	3.0	97.

* Design parameter held to limiting value.

Toxaphene

Table 2
SYSTEM SIZE - March 1989

Design Number	Loadings		Air: Water Ratio	Mass Trans. Coef. (sec-1)	Number of Columns	Column Diameter (ft)	Packing Height (ft)	Air Flow (SCFM)	Air Pressure (inch H2O)
	Liquid (GPM ft-2)	Air (SCFM ft-2)							
1	30.	73.	18.	0.010	1.0	0.8	5.9	41.	2.4
2	30.	110.	27.	0.011	1.0	0.8	14.	60.	3.6
3	30.	120.	31.	0.011	1.0	0.8	20.	69.	4.9
4	30.	140.	35.	0.011	1.0	0.8	34.	77.	8.2
5	30.	73.	18.	0.010	1.0	1.6	5.9	150.	2.4
6	30.	86.	21.	0.011	1.0	1.6	15.	170.	3.2
7	29.	130.	33.	0.011	1.0	1.6	19.	270.	5.0
8	25.	140.	41.	0.0096	1.0	1.7	31.	330.	6.7
9	30.	76.	19.	0.010	1.0	2.8	5.8	470.	2.4
10	30.	110.	28.	0.011	1.0	2.8	14.	700.	3.7
11	30.	130.	31.	0.011	1.0	2.8	20.	780.	5.0
12	28.	140.	36.	0.010	1.0	2.9	33.	910.	7.3
13	30.	73.	18.	0.010	1.0	4.4	5.9	1100.	2.4
14	30.	110.	26.	0.011	1.0	4.4	14.	1600.	3.6
15	30.	120.	29.	0.011	1.0	4.4	20.	1800.	4.7
16	29.	130.	33.	0.011	1.0	4.5	34.	2000.	7.2
17	30.	73.	18.	0.010	1.0	7.3	5.9	3100.	2.4
18	30.	98.	24.	0.011	1.0	7.3	14.	4100.	3.4
19	30.	110.	27.	0.011	1.0	7.3	21.	4600.	4.5
20	29.	120.	31.	0.011	1.0	7.4	35.	5200.	6.7
21	30.	73.	18.	0.010	1.0	11.9	5.9	8200.	2.4
22	30.	91.	23.	0.011	1.0	11.9	15.	10000.	3.3
23	30.	100.	26.	0.011	1.0	11.9	21.	11000.	4.3
24	28.	110.	30.	0.010	1.0	12.2	36.	13000.	6.3

Toxaphene

Table 3
ESTIMATED COST - March 1989

Design Number	Estimated Capital Costs				Operating Cost ($K Year-1)	Yearly Cost ($K Year-1)	Production Cost ($ Kgal-1)
	Process ($K)	Support ($K)	Indirect ($K)	Total ($K)			
1	2.7	7.1	6.4	16.	0.24	2.1	1.04
2	4.1	7.9	7.8	20.	0.34	2.7	1.30
3	5.2	8.5	9.0	23.	0.42	3.1	1.50
4	7.7	10.	12.	29.	0.60	4.0	1.97
5	6.1	12.	12.	29.	0.71	4.1	0.47
6	9.3	13.	15.	38.	0.95	5.4	0.61
7	11.	15.	17.	43.	1.2	6.3	0.71
8	16.	18.	22.	57.	1.6	8.2	0.94
9	10.	18.	18.	46.	1.5	6.9	0.22
10	15.	21.	24.	60.	2.1	9.1	0.29
11	19.	24.	28.	71.	2.6	11.	0.35
12	29.	29.	38.	96.	3.6	15.	0.47
13	16.	27.	28.	70.	3.2	11.	0.14
14	25.	33.	38.	95.	4.4	16.	0.18
15	32.	37.	45.	110.	5.3	19.	0.22
16	48.	47.	63.	160.	7.5	26.	0.31
17	30.	48.	51.	130.	8.3	23.	0.09
18	48.	60.	71.	180.	11.	32.	0.13
19	62.	69.	86.	220.	14.	39.	0.15
20	95.	91.	120.	310.	19.	55.	0.22
21	62.	93.	100.	260.	23.	53.	0.07
22	100.	120.	140.	360.	30.	73.	0.10
23	130.	140.	180.	440.	37.	89.	0.12
24	200.	190.	250.	640.	51.	130.	0.16

Estimated Equipment Size and Cost for Removal of Phase II SOCs from Drinking Water Via Packed Column Air Stripping

March 1989

Compound:

Heptachlor

Henry's Coefficient = 0.034 at 12 Deg. C

U.S. Environmental Protection Agency
Office of Drinking Water
Technical Support Division
Cincinnati, Ohio 45268

Heptachlor

Table 1
DESIGN CRITERIA - March 1989

Design Number	Plant Capacity (MGD)	Average Flow (MGD)	Removal Efficiency (%)	Cost Optimized Parameters	
				Stripping Fractor	Air Gradient (N m-2 m-1)
1	0.024	0.006	60.	1.2*	180.
2	0.024	0.006	70.	1.4	170.
3	0.024	0.006	90.	2.1	120.
4	0.024	0.006	96.	3.5	120.
5	0.024	0.006	97.	3.7	120.
6	0.024	0.006	99.7	4.3	120.
7	0.087	0.024	60.	1.5	160.
8	0.087	0.024	70.	1.8	160.
9	0.087	0.024	90.	2.6	140.
10	0.087	0.024	96.	3.0	140.
11	0.087	0.024	97.	3.1	120.
12	0.087	0.024	99.7	3.6	130.
13	0.270	0.086	60.	1.3	160.
14	0.270	0.086	70.	1.6	150.
15	0.270	0.086	90.	2.3	140.
16	0.270	0.086	96.	2.7	130.
17	0.270	0.086	97.	2.8	130.
18	0.270	0.086	99.7	3.2	120.
19	0.650	0.230	60.	1.2	150.
20	0.650	0.230	70.	1.5	140.
21	0.650	0.230	90.	2.2	120.
22	0.650	0.230	96.	2.5	110.
23	0.650	0.230	97.	2.6	110.
24	0.650	0.230	99.7	3.0	110.
25	1.80	0.700	60.	1.2	130.
26	1.80	0.700	70.	1.4	120.
27	1.80	0.700	90.	2.0	100.
28	1.80	0.700	96.	2.3	99.
29	1.80	0.700	97.	2.4	100.
30	1.80	0.700	99.7	2.8	96.
31	4.80	2.10	60.	1.1	110.
32	4.80	2.10	70.	1.3	100.
33	4.80	2.10	90.	1.9	92.
34	4.80	2.10	96.	2.1	100.
35	4.80	2.10	97.	2.2	100.
36	4.80	2.10	99.7	2.5	99.

* Design parameter held to limiting value.

Heptachlor

Table 2
SYSTEM SIZE - March 1989

Design Number	Loadings		Air: Water Ratio	Mass Trans. Coef. (sec-1)	Number of Columns	Column Diameter (ft)	Packing Height (ft)	Air Flow (SCFM)	Air Pressure (inch H20)
	Liquid (GPM ft-2)	Air (SCFM ft-2)							
1	30.	150.	38.	0.0092	1.0	0.8	11.	85.	4.4
2	26.	160.	46.	0.0084	1.0	0.9	14.	100.	4.8
3	18.	160.	67.	0.0065	1.0	1.1	22.	150.	5.3
4	12.	190.	110.	0.0051	1.0	1.3	24.	260.	5.6
5	12.	190.	120.	0.0050	1.0	1.3	26.	260.	5.9
6	10.	190.	140.	0.0046	1.0	1.4	40.	310.	8.0
7	25.	160.	47.	0.0082	1.0	1.7	9.2	380.	3.8
8	22.	170.	57.	0.0076	1.0	1.9	12.	460.	4.2
9	16.	180.	84.	0.0062	1.0	2.2	20.	680.	5.5
10	14.	190.	98.	0.0057	1.0	2.3	26.	790.	6.4
11	13.	180.	100.	0.0054	1.0	2.4	28.	810.	6.3
12	12.	190.	120.	0.0051	1.0	2.5	44.	950.	9.1
13	27.	150.	42.	0.0086	1.0	3.0	10.	1100.	4.0
14	23.	160.	51.	0.0079	1.0	3.2	12.	1300.	4.3
15	17.	170.	75.	0.0064	1.0	3.7	21.	1900.	5.5
16	15.	180.	87.	0.0059	1.0	4.0	28.	2200.	6.4
17	15.	180.	90.	0.0058	1.0	4.0	30.	2300.	6.7
18	13.	180.	100.	0.0053	1.0	4.3	47.	2600.	9.0
19	27.	150.	40.	0.0086	1.0	4.6	10.	2400.	3.9
20	24.	150.	48.	0.0078	1.0	4.9	13.	2900.	4.2
21	17.	160.	70.	0.0064	1.0	5.7	22.	4200.	5.2
22	15.	170.	81.	0.0059	1.0	6.1	29.	4900.	6.1
23	15.	170.	83.	0.0058	1.0	6.2	31.	5000.	6.3
24	13.	170.	97.	0.0053	1.0	6.6	49.	5900.	8.4
25	27.	140.	37.	0.0084	1.0	7.7	11.	6200.	3.7
26	23.	140.	45.	0.0077	1.0	8.2	13.	7500.	4.0
27	17.	150.	65.	0.0063	1.0	9.6	23.	11000.	4.9
28	15.	150.	76.	0.0058	1.0	10.2	30.	13000.	5.7
29	15.	160.	78.	0.0058	1.0	10.3	33.	13000.	6.0
30	13.	160.	91.	0.0053	1.0	11.0	51.	15000.	8.0
31	27.	130.	36.	0.0082	1.0	12.6	11.	16000.	3.5
32	23.	130.	43.	0.0075	1.0	13.6	14.	19000.	3.7
33	17.	140.	62.	0.0062	1.0	15.8	23.	28000.	4.7
34	17.	150.	68.	0.0062	1.0	16.0	33.	30000.	6.1
35	16.	150.	70.	0.0061	1.0	16.0	36.	31000.	6.5
36	15.	160.	81.	0.0057	1.1	16.0	56.	36000.	8.8

Heptachlor

Table 3
ESTIMATED COST - March 1989

Design Number	Estimated Capital Costs				Operating Cost ($K Year-1)	Yearly Cost ($K Year-1)	Production Cost ($ Kgal-1)
	Process ($K)	Support ($K)	Indirect ($K)	Total ($K)			
1	3.8	7.8	7.6	19.	0.35	2.6	1.28
2	4.6	8.3	8.4	21.	0.42	2.9	1.43
3	7.6	10.	12.	29.	0.63	4.0	1.98
4	9.8	11.	14.	35.	0.84	5.0	2.43
5	10.	12.	15.	37.	0.89	5.2	2.55
6	16.	15.	20.	50.	1.3	7.1	3.49
7	8.4	13.	14.	35.	1.0	5.2	0.59
8	9.8	14.	15.	39.	1.1	5.7	0.65
9	15.	17.	21.	53.	1.6	7.8	0.89
10	19.	20.	25.	64.	2.0	9.5	1.08
11	21.	20.	27.	68.	2.1	10.	1.14
12	31.	27.	38.	95.	3.0	14.	1.62
13	14.	20.	22.	57.	2.2	8.8	0.28
14	17.	22.	25.	64.	2.5	10.	0.32
15	27.	29.	36.	92.	3.7	14.	0.46
16	35.	34.	46.	120.	4.7	18.	0.58
17	38.	36.	48.	120.	5.0	19.	0.61
18	59.	49.	71.	180.	7.2	28.	0.90
19	23.	32.	36.	90.	4.6	15.	0.18
20	28.	35.	41.	100.	5.3	17.	0.21
21	47.	47.	61.	160.	7.9	26.	0.31
22	62.	57.	78.	200.	9.9	33.	0.39
23	67.	61.	84.	210.	11.	35.	0.42
24	110.	86.	130.	320.	15.	53.	0.62
25	45.	58.	68.	170.	12.	32.	0.12
26	56.	65.	79.	200.	14.	37.	0.15
27	96.	93.	120.	310.	20.	57.	0.22
28	130.	120.	160.	410.	25.	73.	0.28
29	140.	120.	170.	430.	27.	78.	0.30
30	220.	180.	260.	660.	39.	120.	0.46
31	96.	120.	140.	350.	32.	74.	0.10
32	120.	130.	170.	420.	37.	86.	0.11
33	210.	200.	270.	670.	54.	130.	0.17
34	280.	250.	350.	870.	69.	170.	0.22
35	300.	270.	370.	940.	74.	180.	0.24
36	480.	400.	580.	1500.	110.	280.	0.37

APPENDIX H

NOTE

This appendix does not contain the following items included as attachments to the original letter:

- Figures 6 and 7 and Table 4 (available as Figures 7-1 and 7-2 and Table 7-6, respectively, in Section 7 of this document).
- Tables of costs for removal of individual Phase II SOCs by GAC (included as Appendix F of this document).
- Tables of costs for removal of individual Phase V SOCs by GAC (available in the Drinking Water docket).

MALCOLM PIRNIE

MALCOLM PIRNIE, INC.
ENVIRONMENTAL ENGINEERS, SCIENTISTS & PLANNERS

March 28, 1990

Mr. Dave Huber
Project Officer
United States Environmental
Protection Agency (WH 550)
Office of Drinking Water
401 M Street, S.W.
Washington, D.C. 20460

Re: Work Assignment 2-14.1
Revision of Granular Activated Carbon (GAC) Process
Empty bed Contact Time (EBCT) and Costs

Dear Mr. Huber:

In May, 1989, USEPA published a proposed rule for Phase II SOCs. Comments from various utilities and organizations, such as American Water Works Association (AWWA), were received by USEPA in response to the proposed rule. The major comment regarding Phase II SOCs was the selection of the most appropriate empty bed contact time (EBCT) for the GAC process, the best available technology for most of Phase II and V SOCs. The GAC process costs were to be revised based on the selected EBCT. According to your request, we have revised the GAC process EBCT and the costs.

In order to revise the GAC process costs for the Phase II and V SOCs, the Adams and Clark (1989) cost model was used. The GAC process EBCT was revised based on a flow frequency distribution analysis of five utilitys' flow data. As a result of the analysis, an EBCT of 10 minutes at design flow was chosen for the USEPA's proposed twelve system sizes. Revised cost estimates were developed based on this new EBCT criteria.

Flow Frequency Distribution Analysis

In order to determine flow frequency distributions, daily water production data from five different size utilities were analyzed. The water production for the selected utilities varied from less than 1 mgd to approximately 200 mgd. The five selected utilities were Cincinnati Water Works, OH, Lake Gaillard Water Treatment Plant, CT, City of Allentown, PA, Village of Ridgewood, NJ and Amawalk-Shenorock Water District, NY. Figures 1 to 5 display the flow frequency distribution analysis for a period of one year for each utility. Based on the frequency distribution analysis, average water production rates, 90th percentile flowrates and their ratios are summarized below:

Utility	Water production Rates (mgd) Average	 90th percentile	Ratio[1]
Cincinnati	124.0	155.0	1.25
Lake Gaillard	35.9	47.3	1.32
Allentown	12.7	17.0	1.34
Ridgewood	6.8	8.7	1.28
Amawalk-Shenorock	0.14	0.17	1.22

1 - 90th percentile/average.

Based on the above analysis, the ratio between 90th percentile and average flowrates was practically constant. Further, flowrates equal to or less than the average flowrates existed for approximately 60 percent of the time. A ratio of 1.35 between 90th percentile and average flowrates was chosen for GAC process design.

GAC Process Design

The existing design of GAC process in the Phase II and V Costs and Technology (C&T) documents assumed an EBCT of 7.5 minutes at design flowrates for the twelve USEPA system sizes. This resulted in EBCTs of 15 minutes or more at average water production rates for all except the three largest system sizes.

In order to revise GAC process EBCT for average, 90th percentile and design water production rates, two options were considered. In first option, an EBCT of 12 minutes was provided at 90th percentile flowrates. EBCTs at average and design flowrates for the 12 system sizes were determined. The second option consisted of an EBCT of 10 minutes at design flowrates and corresponding EBCTs were determined for average and 90th percentile flowrates. The EBCTs for the two options along with the previous design EBCTs in the C&T documents are shown in Table 1.

Option 1 provides an EBCT of 16.2 minutes at average flow rate for the 12 categories. However, EBCTs at design flowrates vary from 3.8 minutes for the smallest to 10.2 minutes for the largest system sizes, respectively.

These EBCTs are short, especially for smaller system sizes, and not considered adequate for GAC process design.

Option 2, based on a 10 minutes EBCT at design flowrate provides a minimum of 15 minutes at the average flowrate for all the system sizes. Further, a minimum EBCT of approximately 12 minutes is provided at 90th percentile flow for the largest system size. Based on literature findings (Hand et al., JAWWA, 1989 and Adams et al., JAWWA, 1989), this EBCT is sufficient for SOCs removal. Further, fouling effects of GAC with background organics may not be significant. Therefore, an EBCT of 10 minutes at design flowrates rates was chosen for all the system sizes. Revised EBCTs at 90th percentile flowrates are similar to the EBCTs at average flowrates in the C&T documents.

Revised GAC Process Costs

GAC process costs for the Phase II and V C&T documents were revised using the Adams and Clark cost model. The following assumptions were used in determining the GAC costs.

- Empty bed contact time of 10 minutes at design flowrate.
- The capital costs included costs for excavation and site work, manufactured equipment, concrete, steel, labor, cast iron and steel pipes and valves, electrical components and instrumentation, and housing.
- Systems smaller than 1 mgd used package pressure contactors.
- Systems between 1 and 10 mgd used pressure contactors.
- Systems larger than 10 mgd used concrete gravity contactors.
- GAC storage is provided for 1.5 times volume of a contactor.
- Cost for land, raw water pumping, chlorination, transfer pumps, bulk potable water storage, finished water pumping and waste disposal were not included.
- Operation and maintenance (O&M) costs for contactors and regenerators, if applicable, included building, process and pump energy, labor, materials and maintenance, and carbon replacement or regeneration costs. These costs were adjusted using a utilization factor which was ratio of average to design flowrates.

- GAC replacement or regeneration costs were based on GAC usage rates as documented in Phase II and V C&T documents.

- If carbon usage was less than 1,000 lb/day (This is a conservative assumption that does not take into account efficient carbon usage attainable with multiple contactors in series or parallel), spent carbon was replaced on SOC breakthrough meeting the MCL. The labor requirements for on-site carbon handling were assumed to be 0.4 hr/1,000 lb of carbon.

- If GAC usage was greater than 1,000 lb/day, spent GAC was regenerated on-site using multiple-hearth furnaces upon meeting the MCL at breakthrough. GAC transport and attrition losses were assumed to be 12 percent. The regeneration furnaces were designed for GAC usage rate corresponding to 90th percentile water production. The operation time for the furnace was assumed to be 120 hr/wk. Therefore, 30 percent downtime including maintenance of furnace was assumed.

- Regeneration furnace costs included the basic furnace, the center shaft drive, furnace and cooling fans, spent GAC storage and dewatering equipment, the auxiliary fuel system, the exhaust scrubbing system, the quench tank, the steam boiler, the control panel, instrumentation, and a building to house the system.

- Water requirements for the carbon transport and regeneration were assumed to be 29 gal/lb of GAC.

- In order to compare the revised GAC process costs with the costs in the C&T documents, revised costs are in late 1987 dollars. The cost indices and the unit costs for power, labor and natural gas are shown in Tables 2 and 3. Table 3 also shows the percentages of the costs allowed for site work, contractors overhead and profit, contingencies, and engineering and technical fees.

- The total capital costs were amortized for a period of 20 years at an interest rate of 10 percent to estimate unit costs.

Figures 6 and 7 show total GAC process costs (cents/1000 gal) plotted as function of GAC usage rates for the 12 flow categories. Table 4 shows the total capital, O&M and total production costs for a range of carbon usage rates and 12 flow categories. Attachments 1 and 2 show GAC process costs for the individual Phase II and V SOCs, respectively. Upon comparing with the C&T documents costs, developed using the CWC model, the revised costs are higher by 10 to 50 percent for different flow categories and GAC usage rates. The differences in the revised costs can be attributed to a longer EBCT and differences in the cost models to develop the costs.

Please do not hesitate to contact us in case you have any additional questions or comments.

Very Truly Yours,

MALCOLM PIRNIE, INC

Thomas J. Lane, PE
Vice President

Harish Arora
Project Engineer

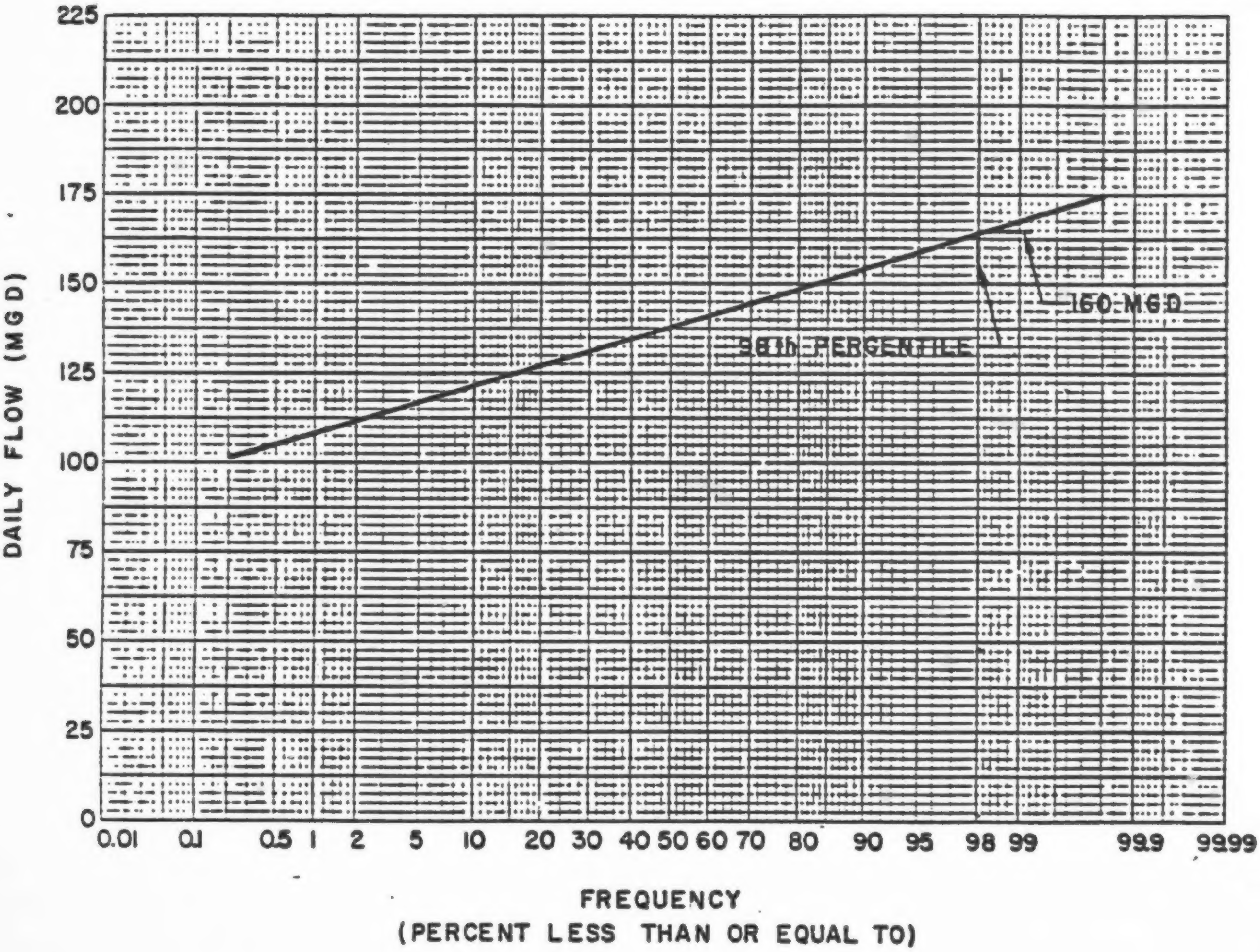
ha

Enclosures

c: Timothy P. Brodeur, MPI
James K. Schaefer, MPI

0313-47-1101

FIGURE 1



FREQUENCY DISTRIBUTION
OF FLOWRATE
AT CALIFORNIA PLANT

FIGURE 2

FLOW FREQUENCY DISTRIBUTION
LAKE GAILLARD WATER TREATMENT PLANT, CT

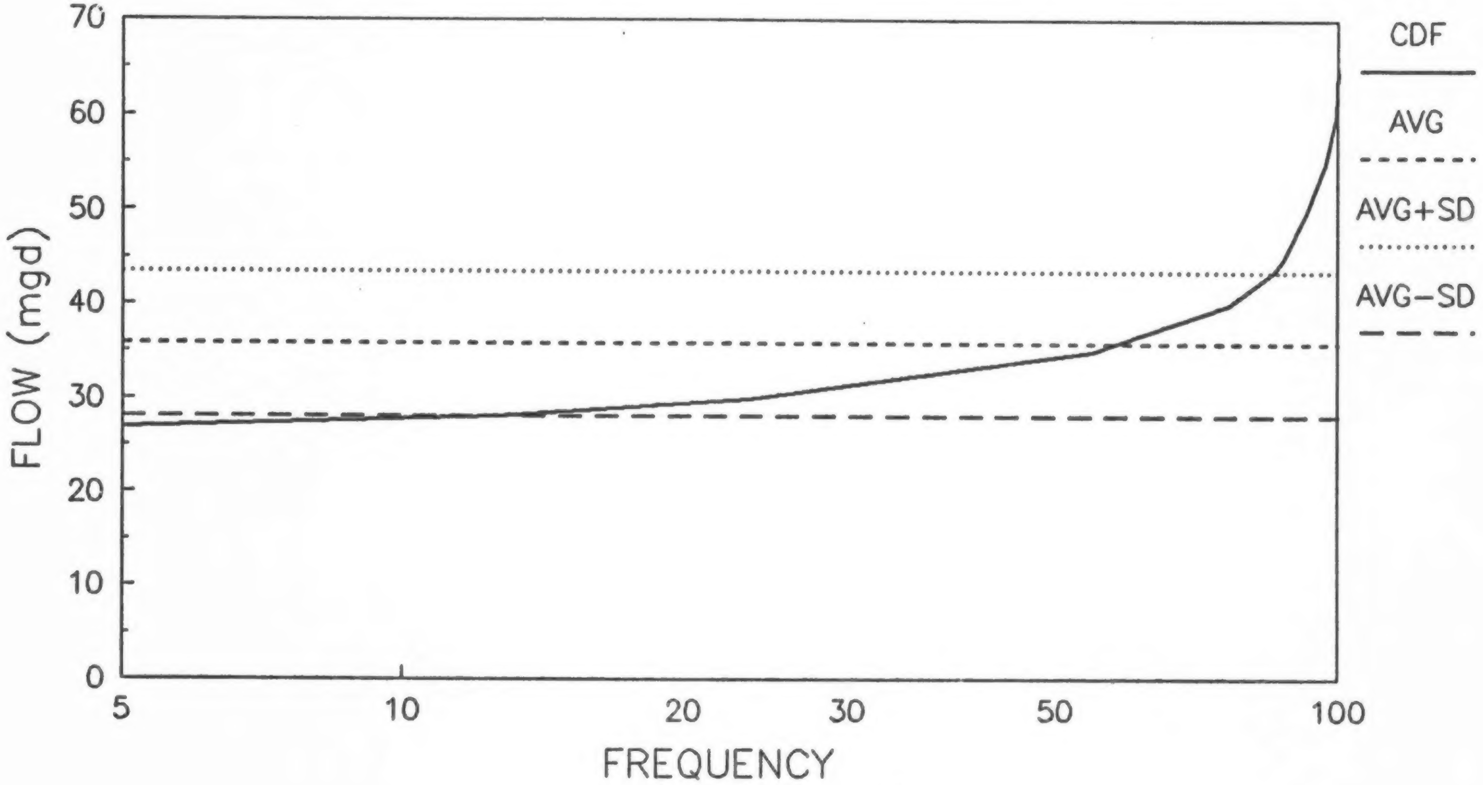


FIGURE 3

FLOW FREQUENCY DISTRIBUTION
CITY OF ALLENTOWN, PA

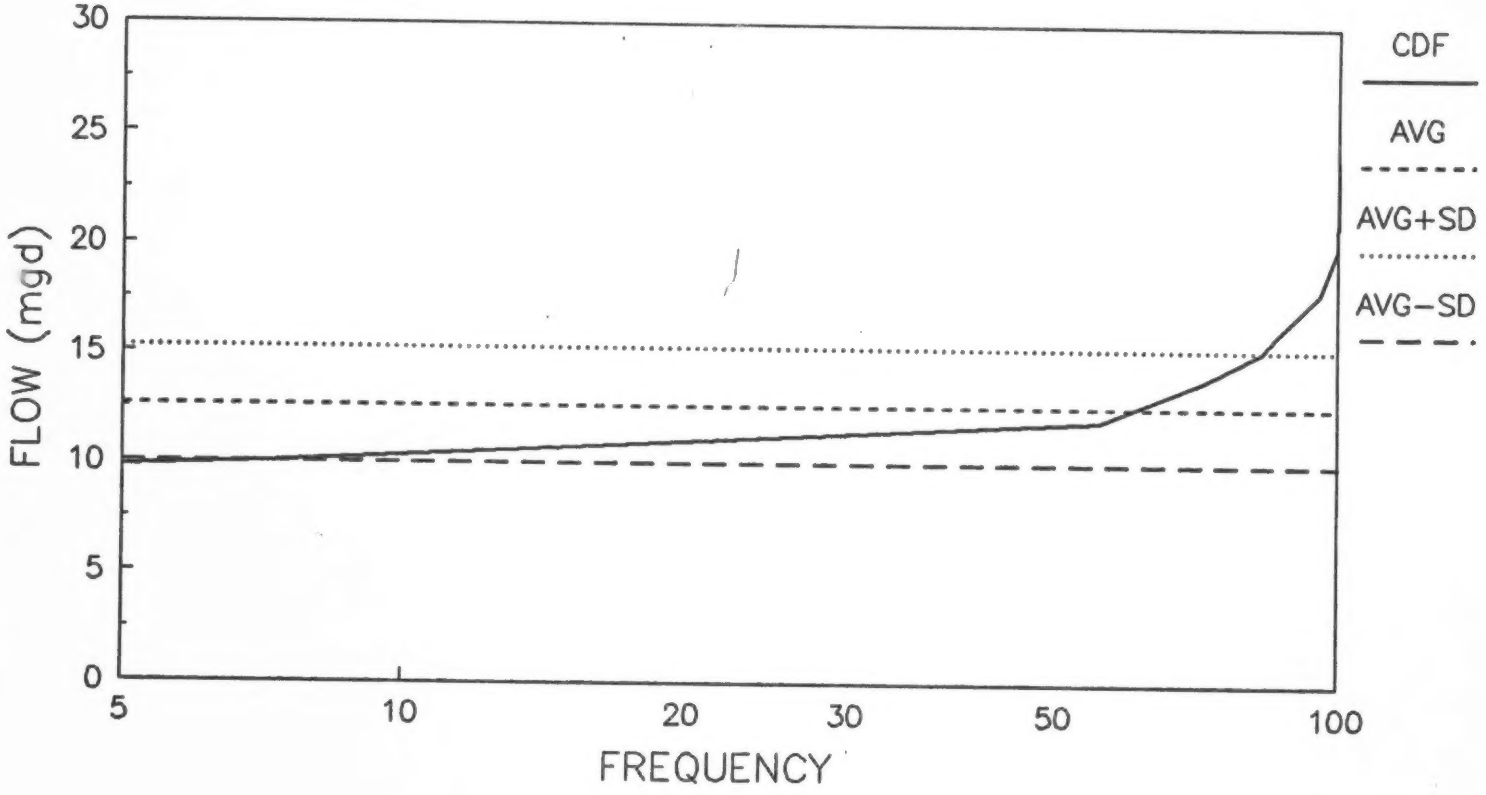


FIGURE 4

FLOW FREQUENCY DISTRIBUTION
VILLAGE OF RIDGEWOOD, NJ

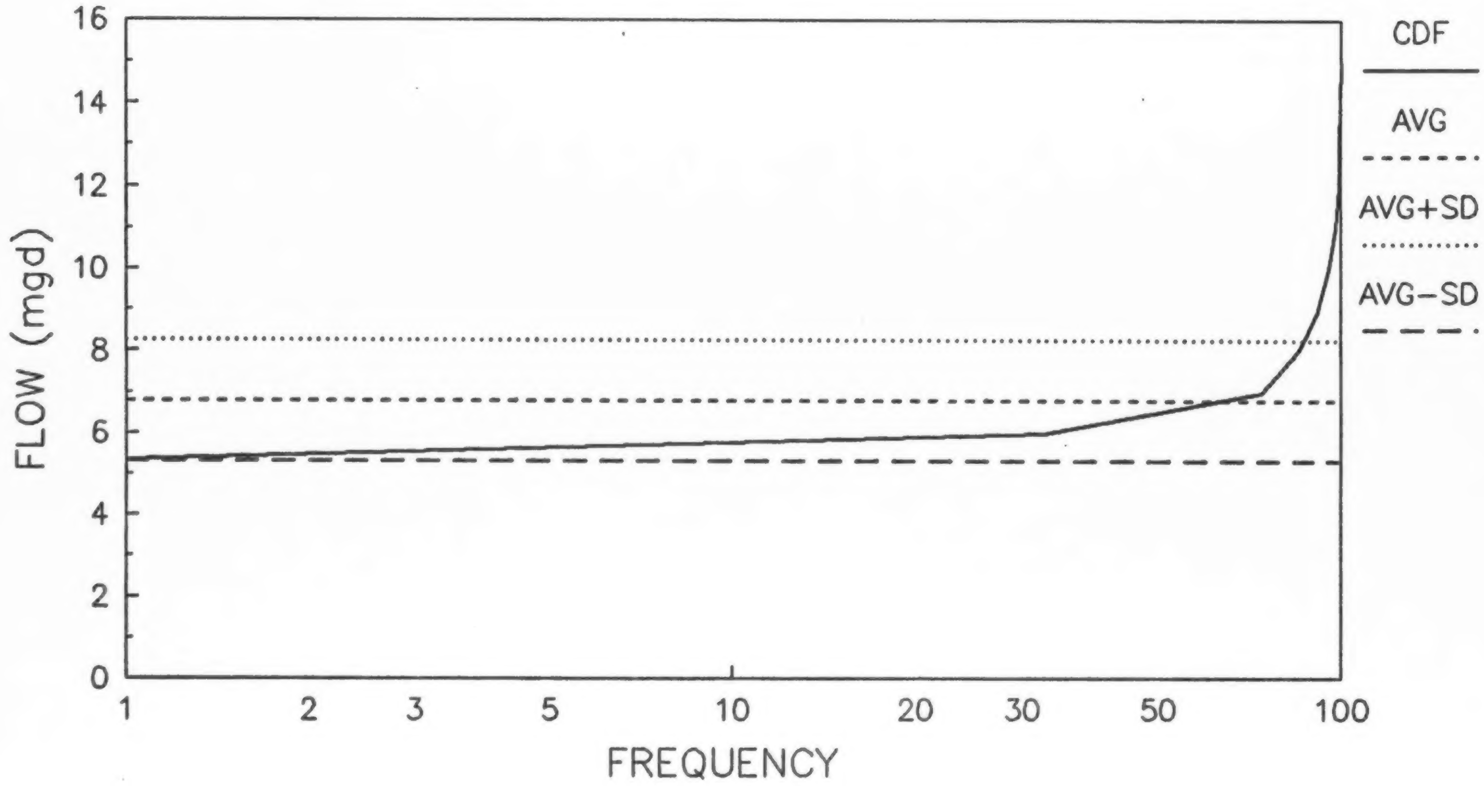


FIGURE 5

FLOW FREQUENCY DISTRIBUTION
AMAWALK-SHENOROCK WATER DISTRICT, NY

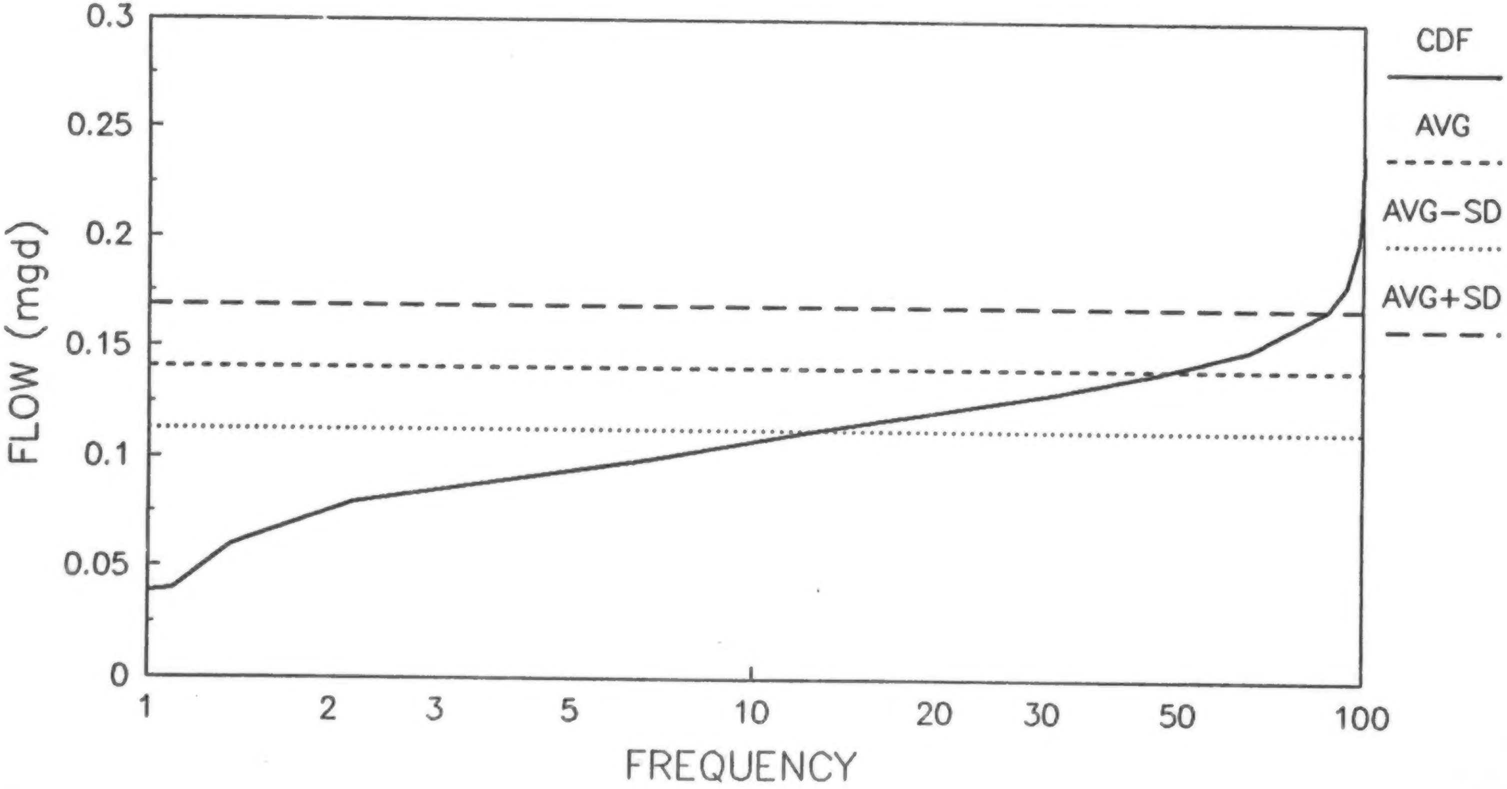


TABLE 1

System	Water Production Rates (mgd)			Empty Bed Contact Times (min)								
				Existing (C&Ts)			Option # 1			Option #2		
	Average	Design	90 percent	Average	Design	90 percent	Average	Design	90 percent	Average	Design	90 percent
1	0.0056	0.024	0.008	32.1	7.5	23.8	16.2	3.8	12.0	42.9	10.0	31.7
2	0.024	0.087	0.032	27.2	7.5	20.1	16.2	4.5	12.0	36.3	10.0	26.9
3	0.086	0.27	0.12	23.5	7.5	17.4	16.2	5.2	12.0	31.4	10.0	23.3
4	0.23	0.65	0.31	21.2	7.5	15.7	16.2	5.7	12.0	28.3	10.0	20.9
5	0.70	1.8	0.95	19.3	7.5	14.3	16.2	6.3	12.0	25.7	10.0	19.0
6	2.1	4.8	2.8	17.1	7.5	12.7	16.2	7.1	12.0	22.9	10.0	16.9
7	5.0	11	6.8	16.5	7.5	12.2	16.2	7.4	12.0	22.0	10.0	16.3
8	8.8	18	11.9	15.3	7.5	11.4	16.2	7.9	12.0	20.5	10.0	15.2
9	13	26	17.6	15.0	7.5	11.1	16.2	8.1	12.0	20.0	10.0	14.8
10	27	51	36.5	14.2	7.5	10.5	16.2	8.6	12.0	18.9	10.0	14.0
11	120	210	162	13.1	7.5	9.7	16.2	9.3	12.0	17.5	10.0	13.0
12	270	430	365	11.9	7.5	8.8	16.2	10.2	12.0	15.9	10.0	11.8

Table 2

Cost Indices For Late 1987

Description	Index Reference	Numerical Value
Producer Price Index	Department of Labor	296.7
Construction Cost Index	ENR	412.4

Table 3

General Assumptions Used In Developing Costs

Electrical Power	$ 0.086/Kwh
Labor - Small Systems (<100,000 gpd)	$ 5.9/hr
- Large Systems (>100,000 gpd)	$ 14.3/hr
Diesel Fuel	$ 0.80/gal
Natural Gas	$ 0.0027/scf
Sitework	15% of construction costs
Contractor's Overhead and Profit	12% of construction costs (including sitework)
Contingencies	15% of construction costs
Engineering and Fees	15% of construction costs (including sitework and contractor's O&P)
Interest Rate	10 %
Number of Periods	20

APPENDIX I

MALCOLM PIRNIE, INC.

Date: February 26, 1990

To: Dave Huber, ODW, USEPA

From: Harish Arora, MPI

Re: Phase II and V SOCs

As we talked, I have categorized Phase II and V SOCs based on their strippabilities and vapor phase adsorbabilities. This matrix is based on USEPA's set MCLs and range of removal efficiencies. Vapor phase adsorbability for compounds with no data were based on their liquid phase GAC adsorbabilities. Therefore, this categorization should only be used as guidelines as for a given compound air to water ratio may increase with an increase in removal efficiency.

	Vapor Phase Adsorbability		
Strippability	Poor	Moderate	Strong
Phase II and V SOCs:			
Good	cis-1,2-Dichloroethene trans-1,2-Dichloroethene	Ethyl benzene Monochlorobenzene Tetrachloroethene Toluene Xylenes	HCCPD 1,2,4-TCB
Average	1,2-dichloropropane 1,1,2-Trichloroethane Dichloromethane		o-Dichlorobenzene Styrene
Difficult	Ethylene dibromide z	DBCP z	Hexachlorobenzene

Please contact me if you have any questions or comments.

c: Jim Schaefer

DRAFT

ATTACHMENT - I

COSTS FOR PACKED COLUMN AIR EMISSION CONTROL
- VAPOR-PHASE GAC -

Assumptions:

1. Capital costs were developed for the following A:W ratios for each system size:

   - 40:1
   - 120:1
   - 200:1

2. Capital costs included:

   - Carbon contactor
   - Initial GAC Charge
   - Blower
   - Heater
   - Ductwork
   - Gas piping
   - Concrete slab

3. Carbon contactor was designed based on an air loading rate of 75 to 100 ft per min:

Airflow (cfm)	Contactor Diameter (ft)	Bed Depth (ft)	No Of Contactors
5,000	10	3	1
50,000	10	6 (1)	4
500,000	12	6 (1)	24

(1) Dual-bed construction

4. Influent air to the contactor was heated to lower the relative humidity from 100 to 50 percent.

5. Costs were based on quotations from vendors.

6. O&M Costs included:

   - GAC Replacement
   - Natural gas
   - Power
   - Material

6. GAC replacement costs were estimated for three cases:

Vapor Phase Adsorbability	Carbon Capacity (gm SOC/gm GAC)
Poor	0.03
Moderate	0.05
Good	0.08

7. Carbon replacement cost was $2/pound; Natural gas was $0.47/therm.

10,852
5,594

5/2

Estimated Cost for Vapor Phase Control with GAC

System Size Category Population Range Design Flow (MGD) Average Daily Flow (MGD)		ADSORPTION CAPACITY								
		POOR			MODERATE			STRONG		
	Air: Water Ratio	40	120	200	40	120	200	40	120	200
25-100	Total Capital Cost (K$)	46	58	65	46	58	65	46	58	65
0.024	O&M Cost (K$/year)	0.20	0.30	0.30	0.20	0.20	0.20	0.10	0.20	0.20
0.0056	Total Production Cost (cents/1,000 gal)	270	330	390	270	340	380	270	340	380
101-500	Total Capital Cost (K$)	60	78	89	60	78	89	60	78	89
0.087	O&M Cost (K$/year)	1.0	1.2	1.4	0.6	0.8	1.0	0.4	0.6	0.8
0.024	Total Production Cost (cents/1,000 gal)	90	120	140	87	114	130	85	111	130
501-1,000	Total Capital Cost (K$)	79	110	135	79	110	135	79	110	135
0.27	O&M Cost (K$/year)	4	4	5	2.3	3.0	3.7	1.6	2.3	3.0
0.086	Total Production Cost (cents/1,000 gal)	41	54	70	37	51	62	35	48	60
1,001-3,000	Total Capital Cost (K$)	100	160	210	100	160	210	100	160	210
0.65	O&M Cost (K$/year)	10	12	13	6	8	10	4	6	8
0.23	Total Production Cost (cents/1,000 gal)	25	37	45	21	32	41	19	30	39
3,001-10,000	Total Capital Cost (K$)	150	280	380	150	280	380	150	280	380
1.8	O&M Cost (K$/year)	29	35	40	19	25	30	13	18	24
0.7	Total Production Cost (cents/1,000 gal)	18	27	33	14	23	29	12	20	27
10,001-25,000	Total Capital Cost (K$)	260	560	900	260	560	900	260	560	900
4.8	O&M Cost (K$/year)	88	100	120	56	74	90	38	55	73
2.1	Total Production Cost (cents/1,000 gal)	15	22	29	11	18	26	9	16	23
25,001-50,000	Total Capital Cost (K$)	440	1200	2000	440	1200	2000	440	1200	2000
11.0	O&M Cost (K$/year)	210	250	290	130	180	220	90	130	170
5.0	Total Production Cost (cents/1,000 gal)	16	21	29	10	18	25	8	15	22
50,001-75,000	Total Capital Cost (K$)	700	1900	3100	700	1900	3100	700	1900	3100
18.0	O&M Cost (K$/year)	370	440	510	240	310	380	160	230	310
8.8	Total Production Cost (cents/1,000 gal)	14	21	27	10	17	23	8	14	21
75,001-100,000	Total Capital Cost (K$)	970	2700	4200	970	2700	4200	970	2700	4200
26.0	O&M Cost (K$/year)	550	660	750	350	460	570	240	340	450
13.0	Total Production Cost (cents/1,000 gal)	14	21	26	10	16	22	7	14	20
100,001-500,000	Total Capital Cost (K$)	1800	5000	7900	1800	5000	7900	1800	5000	7900
51.0	O&M Cost (K$/year)	1100	1400	1600	700	950	1200	500	710	940
27.0	Total Production Cost (cents/1,000 gal)	13	20	26	9	16	22	7	13	19
500,001-1,000,000	Total Capital Cost (K$)	6600	18000	28000	6600	18000	28000	6600	18000	28000
210.0	O&M Cost (K$/year)	5000	6100	7000	3200	4200	5200	2200	3100	4200
120.0	Total Production Cost (cents/1,000 gal)	13	19	23	9	14	19	7	12	17
>1,000,000	Total Capital Cost (K$)	13000	34000	54000	13000	34000	54000	13000	34000	54000
430.0	O&M Cost (K$/year)	11300	14000	15600	7200	9500	12000	5000	7100	9400
270.0	Total Production Cost (cents/1,000 gal)	13	18	22	9	14	19	7	11	16